EFFECT OF TEMPERING TEMPERATURE AND TIME ON STRENGTH AND HARDNESS OF DUCTILE CAST IRON

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CERTIFICATE

This is to certify that the thesis qualified, **“Effect of Tempering Temperature and Time on Strength and Hardness of Ductile Cast Iron”** submitted by **Ravindra Kumar** (**710MM1165**) for requirements Master of Technology degree in metallurgical & Materials Engineering at National Institute of Technology, Rourkela is a genuine work carried out under my guidance and supervision.

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ABSTRACT

The use of ductile cast iron is as an engineering materials has been increase day by day.it is widely used in manufacturing industry. It have excellent combination of mechanical properties due to same heat treatment process at different time and temperature. It have an excellent combination of tensile strength, wear resistance, good corrosion resistance, good ductility, toughness, impact strength, by using different types of heat treatment process. The effects of tempering temperature and time on the mechanical properties of ductile cast iron is investigated in the current work. The all sample were austenitized at 900°C for 120 minutes and then quenched in mineral oil at room temperature. After quenching the specimens were tempered at 400°C and 200°C for 60min, 90min, and 120min, respectively. In the tempering temperature range of 200°C - 400°C, there is sudden increase in impact strength, ductility and toughness of the materials, as the temperature and time increase. The Ultimate tensile strength drops initially, and hardness of materials will also depends on amount of matrix phase of martensitic and retain-austenitic/ferrite and graphite nodules. In this work alloying elements also effected the microstructure of the specimen. And due to increase tempering time the amount of martensitic phase will decrease and austenitic phase will increase, austenitic phase is softer then martensitic so hardness will decrease. and sample treated to ball on plate wear tester under 20N load at constant speed 10rpm with different times 10min, 20min, 30min for sliding distance 4mm track diameter respectively of same sample. Weight loss was observed in all sample after wear test, the wear resistance was calculated according to the ASTM G 65 standard, and the result showed that in all cases, when the nodules count and nodularity increase the wear resistance decrease and when tempering time and temperature increase the wear resistance will also effected. And by XRD investigate the different matrix and volume fraction, peak analysis.

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CHAPTER 1

1:- INTRODUCTION

Ductile cast Iron is likewise called to as “Spheroidal Graphite” iron or “nodular Iron” it is a kind of cast iron designed in 1943 by Keith Millis. While highest of the diversities of cast iron have brittle behavior. But ductile iron has much extra impact strength and fatigue resistance, because of its nodular graphite inclusions [1]. It was produced 1948 in American Foundry men’s Society Annual Conference. J.W. Bolton, taking at the 1943 Convention of the American Foundry men’s Society (AFS) going to make cast iron - an as-cast "gray iron" with mechanical properties equivalent or better to Malleable Iron [3]. A couple of weeks after the fact, in the International Nickel Company Research Laboratory, Keith Dwight Millis made a ladle addition of magnesium (as a copper-magnesium alloy) to cast iron and supported Bolton's idealism –after casting they absorbed the solidified castings not contained flakes, but rather about perfect spheres of graphite which is called graphite nodules[4]. After five years, at the 1948 AFS Convention, Henton Morrogh of the British Cast Iron Research Association reported that they also produced of spherical graphite successfully in hypereutectic gray iron by the mixing of small amounts of cerium. Ductile Iron is also called a high strength nodular cast iron. It have excellent engineering properties. Ductile cast iron have spherical graphite nodules in its internal/inward structure. It have uncommon combination of properties because the graphite formed as spheroids nodules slightly than flakes as in grey iron. The shape flakes of graphite create more stress concentration at a points or edges flakes within the metal phases and the rounded structure of the nodules less stress concentration so, thus preventing the formation of cracks and providing the higher ductility properties that gives also the same specifics alloys[6]. This method of hardening is gotten by including A Small amount of Mg & Ce or both they are Maine reasons the flake graphite to take on a spheroidal shape.

The including Mg reacts with S or O in the molten condition or liquid cast iron and because of that reaction graphite will formed on shape. It's have good fluidity, good wear resistance, excellent machinability, high strength, reasonable toughness and ductility [7]. It's Application in as like Door lock, Crankshafts, gears and rollers, pressure castings such as valve and pump bodies, and huge press rolls. Due to presence of high amount of carbon and silicon element of ductile iron give the casting procedure with a couple of profits, but the graphite nodules have only a significant effect on the mechanical properties of the metal. Ductile iron shows a linear stress-strain relation, a significant variety of yield strengths. Different types of Castings are made in an extensive variety of sizes with segments that can be either thick or thin [11]. Flexibility of Ductile Iron, are provides the greatest combination of overall properties. That adaptability is particularly apparent in the area of mechanical properties whereas Ductile Iron proposals the formation of different type of designs with the option of choosing high ductile metal, with have more than 18% elongation, or high strength, with tensile strengths exceeding (825 MPa). Austempered Ductile Iron (ADI), suggestions more mechanical properties and wear resistance, and it have tensile strengths exceeding (1600 MPa) [21]. When compared to Ductile Iron with steel castings, it also suggestions additional cost savings. Its most commercial cast metals, Malleable Iron and steel reduction in volume during solidification, therefore it require connected stores (feeders or risers) of liquid metal to counterbalance and prevent the formation of interior or outside shrinkage imperfections.

The formation of graphite nodules/flack during solidification are Maine reason an internal expansion properties of Ductile Iron [26]. It may be provided cast free of important shrinkage the elimination or reduction of feeders can be obtained by only appropriately design castings. This reduction necessities for increases feed metal and productivity of Ductile Iron increases and decreases energy requirements of material and it resulting in considerable cost savings process.

1.1 Production of ductile cast iron

Ductile cast iron is also known as nodular cast iron or spheroidal graphite cast iron. It is made by treating molten iron of proper composition of Mg & Ce or both before casting. They help to formation of graphite in the form of separate nodules in its place of inter connected flakes [28]. It have good fluidity, good wear resistance, excellent machinability, high strength, reasonable toughness and ductility.

Following factor is also important for production of ductile cast iron

- **Desulphurization:** Sulphur helps in the development of graphite flakes. But for ductile cast iron we want graphite nodules. Therefor at producing ductile cast iron the Sulphur content should be low as like less < 0.1% in raw materials. Therefor during melting Sulphur should be eliminate by addition of a desulphurising agent as like calcium carbide or soda ash.
- **Nodularizing:** Small amount of Magnesium is mixed with bath to stalemate up Sulphur and oxygen and then drastically change in the graphite growth mechanism. When Magnesium treat with oxygen it form highly stable MgO and which is floats on the molten surface and can be removed easily [19]. It reduces levels from of 90-135ppm to about 15-35ppm.when Magnesium treated with Sulphur than it form less stable MgS. Because of magnesium have low solubility and volatile nature of in the metal and, reaction can become reversible if Si is added for additional deoxidation. Other things Cerium is also forms highly stable oxides with Sulphur and Oxygen and it's have less volatile than Mg.

  Addition of Mg is done when the materials melt is at 1500°C but Mg vaporizes at 1100°C. Magnesium is lighter then it floats on bath and it's more reactive then it burn off at the surface. For saving Mg we generally added as Ni-Mg, Ni-Si-Mg alloy or magnesium coke to reduce chemical reaction. Therefore magnesium plays an important role in the manufacture of ductile cast iron [15]. After nodulising treatment inoculants like Mg providing their nodulising effect on the graphite structure therefor the graphite nodules can be formed.

- **Inoculation:** before the metal molt or either during pouring the small amount of inoculation of cast iron added. Therefore Inoculation increases the precipitation and consequent growth of graphite. This effect is increasing the degree of nucleation growth of cast iron. It can be assumed that high levels formation of graphite structure whilst low levels of formation of either mottled structure or white irons [15].

  When cooling rate increases, the requirement for a high level of nucleation is also increases and segment size decreases. The main purpose of addition of inoculation, is an important in maintaining good nodule shape and also increase more numbers of nodules. Graphite are not more effective inoculants for ductile cast irons. Basically based on silicon all inoculants are more effective. Ferrosilicon generally used in foundry grade, containing about 75% silicon. This alloy also must contain small amounts of Al and calcium, the amounts of required are about 1.5-2.05 aluminum and approx. about calcium 0.3-1.0%. The inoculating effect initially increases as the amount of inoculants is increased in the materials. This partially reimburses for their increased cost and has the advantage of reducing the amount of silicon contained.

- ## Solidification of Ductile cast iron:

Solidification of Ductile cast iron is continuously related with correct under cooling. Graphite nuclei growth gradually and then it enclosed by austenite. The formation of austenite and graphite corresponds of eutectic point at the eutectic temperature. Austenite gets supersaturated position with carbon. And at the graphite/austenite interface new equilibrium stage is established. The extra carbon diffuses towards the graphite nodule which is precipitates out.

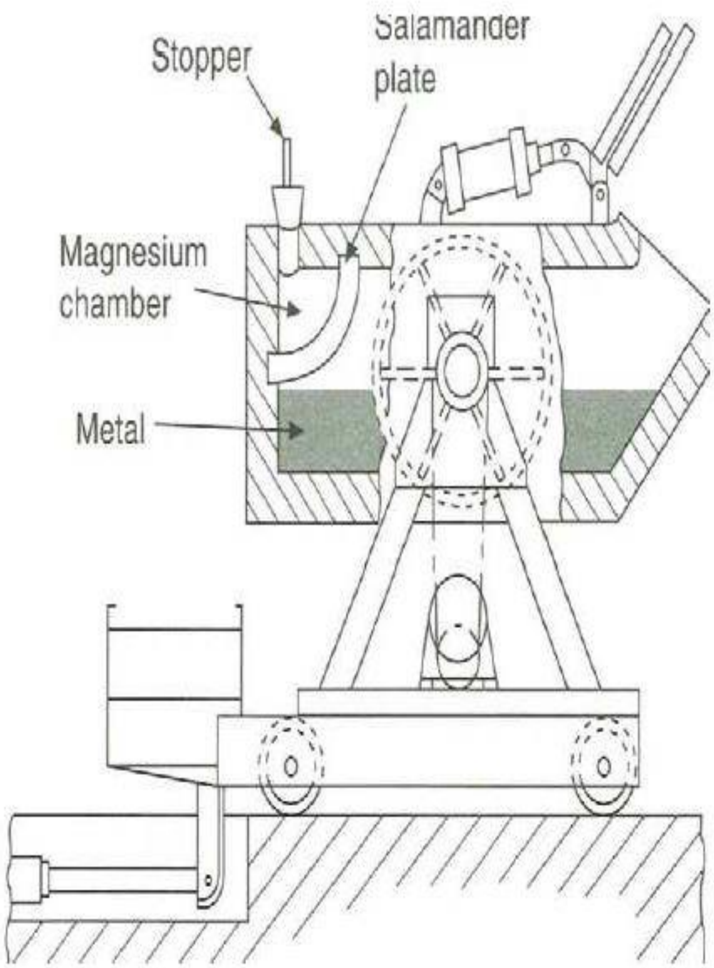


Fig 1.1: G.F. Fisher Method for production of ductile iron

1.2 Types of Cast iron and ductile cast iron

- ### Types of cast iron

Cast irons mostly contain more than 2% Carbon with multiplicity of alloying elements. Classification of cast iron is done on the basis of the presence of their mechanical properties and fracture surface and their microstructure with a different matrix phases. basically two class of cast irons historically, one having a gray fracture and another having a white fracture, which is called gray cast iron and white cast iron respectively [6]. Those cast irons having both gray and white properties are called mottled iron. Other type of cast irons have been developed in 19 century which have their name on their mechanical property, such as malleable iron and ductile iron. More recently in ductile cast iron have compacted graphite iron and austempered ductile iron have been introduced.

There are four elements which lead to the different types of cast irons namely,

1) The Amount of carbon content,

2) Different type of alloy elements content

3) The Amount of impurity content,

4) The cooling rate and the heat treatment after casting.

These factors control the composition as well as the form of parent matrix phase present.

Classification of different types of cast iron.

1. **Gray cast iron:**
2. **White cast iron:**
3. **Malleable cast iron:**
4. **Ductile cast iron:**

1. Gray cast irons:

Gray cast iron is the very popular type of cast iron and it is easily found. It has a high amount of graphite flakes therefor it have gray crack surface. Carbon is more stable than carbide form at graphite form. At a cooling time if it's controlled cooling rate and negligible alloying addition then carbon gets precipitated out as graphite flakes. Gray cast iron has high amount of Si content therefor it is help the formation of graphite flakes during solidification. It have minor ductility properties but it is very useful because they have a properties to easily casted to complex shapes and it is very economical. It is also have much low impact resistance.

2. White cast iron:

White cast iron developed by quick solidification of gray iron. It has white crack surface. This type of cast iron does not content Graphite flakes.it have iron carbide network in our surface whose are gives white fracture surface [3]. Low amount of Si content is reduce the graphitizing effect. It is has very hard surface and have good abrasion resistance. But it is also have unnecessary brittleness and low machinability. For improve its wear resistance we are generally added Mo, Cr, Ni, in it.

3. Malleable cast iron:

Malleable cast iron is developed by heat treatment of white cast iron. When white cast iron heat treated at high temperature then the presence of iron carbide network breaks down into temper carbon. This treatment is called malleablization. It is contains two stages of annealing processes. It have two stages of annealing processes. As in the first stage of annealing and other the second stage of annealing. Malleable cast iron becomes malleable, Due to absence of hard phase and brittle carbide phase. Malleable cast iron is one of the important engineering materials which possesses good properties such as cast ability, machinability, good corrosion resistance strength, toughness.

5. Ductile cat iron:

It's developed by adding special alloying elements and proper cooling rates therefor the carbon can be easily transformed to spherical graphite nodules. The graphite nodules are formed during solidification and not at heat treatment [3]. It have three different types of cast iron, ferritic, pearlitic/ferritic, and martensitic. Ductile cast iron have good mechanical properties which can be equivalent to steels. Austempered ductile iron is the subclass of ductile cast iron. It has the same spherical graphite nodules as like in ductile iron but it have different the matrix phase. Which is a combination of bainite and stabilized austenite. In ductile cast iron have graphite nodules in compact form and shape of graphite nodules are controlled by same alloying element. Austemperd ductile irons have good mechanical properties such has tensile strength, wear resistance and ductility.

Different types of Ductile cast iron

Ductile cast iron have high amount of graphite nodules in the structure, therefor its mechanical properties are depend on the ductile cast Iron matrix. Matrix phase is depend on heat treatment processes and different types of alloying elements presence in melting processes.

Depending on the matrix phases, ductile cast iron can be classified into four different groups.

1. Ferritic

2. Pearlitic

3. Martensitic

4. Austentic

Ductile cast irons are mostly ferritic type of cast iron. But it's not used in certain applications because it have high ductility and low yield strength. Thus if some amount of carbon are presence in cementite form then its property gets improved. This type of ductile iron is called as pearlitic ductile iron. If the cooling rate is very high then the matrix phase of ductile cast iron will get converted into martensite. It have limited applications because of its ductile nature

1.3 Chemical composition of ductile cast iron

Chemically Ductile cast iron are equally as grey iron. Ductile cast iron obtained many combination of properties because the graphite phase have a spheroids nodules rather than flakes in the grey cast iron. Same main alloying elements present in ductile iron can have effect on the microstructure and change the properties of cast iron. Exception of silicon, all alloying elements promote pearlite formation and nickel and copper also promotes carbide formation. Those alloying elements are go in to solution which mostly increased the Properties of ferritic of the ductile iron. Exception of carbon, all alloying elements increase the tensile strength and hardness. For example ferrite is affected by solid solution strengthening it is explained by silicon and nickel content. When 1% of Si added in solution it increase the resistant and tensile strength of a ferritic iron of the ductile cast iron by approximately 82 N/mm2. Whereas adding of 1% of nickel increases these properties by 46 N/mm2. Ductile cast iron become embrittled if ferritic iron increase tensile strength and resistant strength [31]. Graphite flakes have sharp and edge shape due to sharp edge it create more stress concentration at sharp and edge points within the surface matrix and rounded shape of graphite nodules create very less stress concentration, therefor it preventing the cracks and providing higher ductility all their properties gives by adding same alloying elements.

This method of solidification is become by adding a small amount of Mg & Ce or both, it causes a spheroidal shape of the flake graphite. The added Mg which is reacts with S and or O in the molten cast iron and due to that reaction graphite will formed.

A Typical chemical composition of ductile cast iron.

1. Amount of Carbon 3.2 to 3.6%
2. Amount of Silicon 2.2 to 2.8%
3. Amount of Manganese 0.1 to 0.5%
4. Amount of Magnesium 0.03 to 0.05%
5. Amount of Phosphorus 0.005 to 0.04%
6. Amount of Sulfur 0.005 to 0.02%
7. Amount of Copper <0.40%
8. Amount of Iron = balance

Other types of elements also added as like copper or tin to increase tensile and yield strength whereas suddenly reducing ductility. And if amount of nickel, copper, and chromium added with replacing 15% to 30% of the iron to improved corrosion resistance [2].

1.4 Different types of microstructure of ductile cast iron

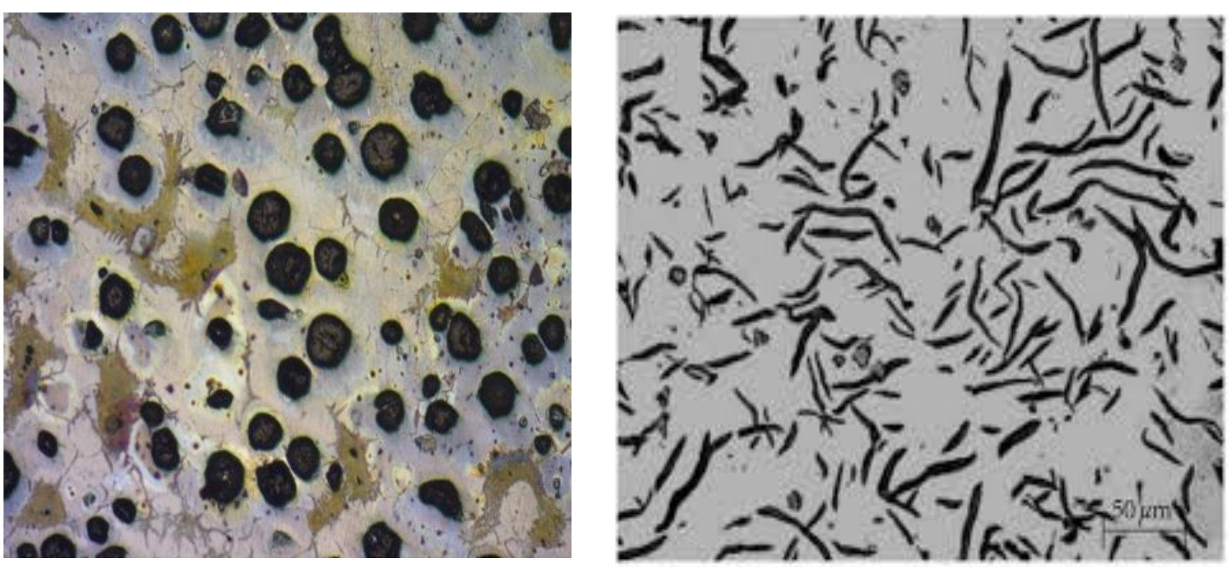


Fig1.2: Microstructure of ductile cast iron and gray iron

Cast iron are the most used materials in engineering manufacturing. They belong to a family of ferrous alloys. Application of cast iron have been based upon gray irons or flake graphite which are providing an different range of tensile strengths between 150 N/mm² and 400N/mm² with suggested design stresses in tensile applications of 0.25 x tensile strength. Different types of ductile irons have tensile strengths ranging between from 350 to 1500 N/mm² with excellent elongation and high toughness. Difference between ductile iron and grey iron is only the graphite formation in the microstructure. Which is flake like or spherical nodules they form after proper treatments and with the help of same alloying elements.

1.5: Ductile or brittle behavior of ductile cast iron

All ferrous materials, with the exception of the austenitic grades shows a transition from ductile to brittle behavior when tested above and below a certain temperature known as transition temperature. A comprehensive treatment of the subject by Barton has been used to identify and discuss some of the factors affecting Ductile and Brittle behavior as follows. Ductile failure is accompanied by considerable general or local plastic deformation, usually shown by visible distortion of a failed component and by slow crack extension or tearing. A ductile fracture appears black in a fully ferritic ductile iron and gray in pearlitic irons. Ductile fractures occur by tearing from the sites of graphite nodules along grain boundaries. So that, the fracture contains numerous graphite nodules. Brittle failure, by contrast, generally occurs without deformation, and very rapid crack propagation is involved. Brittle fractures in ductile irons are not associated with graphite sites and occur by cleavage of the metallic grains, usually before significant deformation has occurred. The separation through the grains very rapid and such fractures appears bright because the cleavage facets of the grains reflect light, a brittle fracture characteristically passes through the grains and very few, if any, graphite nodules are present along the fracture path. The transition temperature of a material is raised if loading speeds are high or if a notch is present. For this reason, brittle fractures are more commonly observed during impact testing then there during normal tensile testing. It is important to appreciate, however, that brittle failure can occur under normal tensile loading if the conditions favour this mode of failure. A simplified explanation for this ductile – to – brittle transition behavior is shown in figure 1.7, At higher temperatures, the stress required to cause plastic deformation is relatively low and failure occurs in a ductile manner, with considerable deformation, before the stress to trigger brittle failure by cleavage is exceeded. The stress required to cause plastic yielding increases rapidly as the temperature is decreased, and the stress required to produce brittle fracture may then be exceeded before plastic yielding can take place.

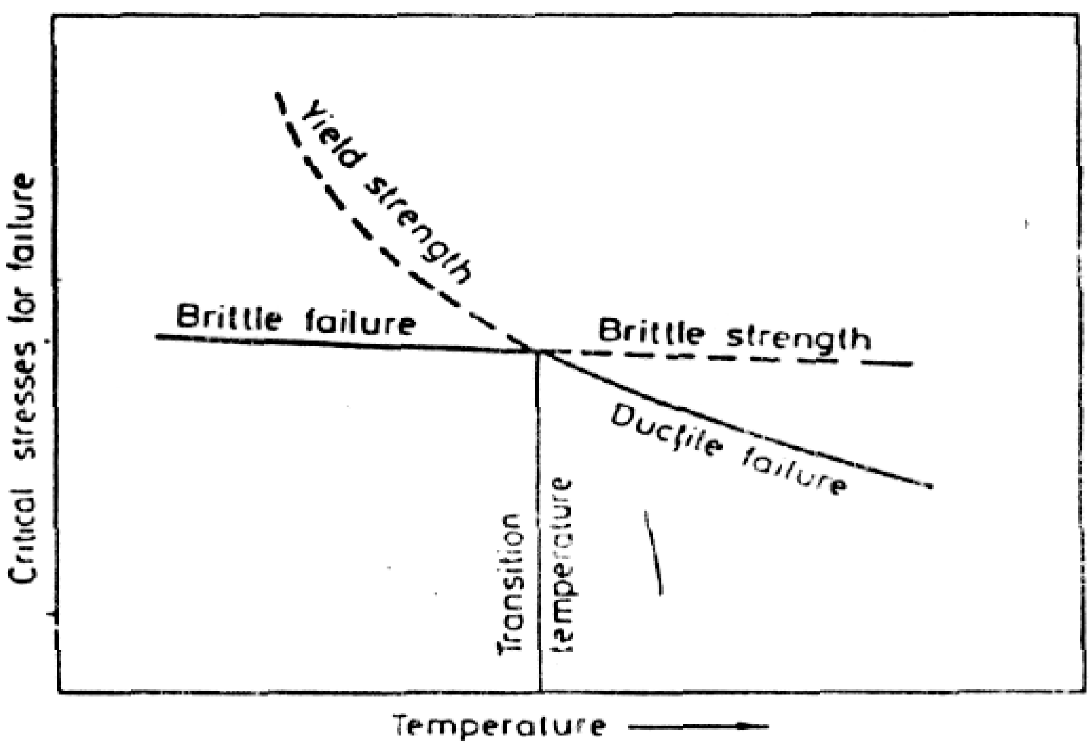


Fig 1.5: Ductile to Brittle transition occurs as temperature increases.

2. A BRIEF REVIEW OF PREVIOUS WORK ON DUCTILE CAST IRON

From the accessible writing and study materials, it is truly denoted that numerous endeavors were made to comprehend and expect the practices of bendable iron that incorporates the investigation of graphite morphology, its properties and its advancement, the change of grid structure by the diverse warmth treatment, and we think about structure and properties relationship and its mechanical properties and conceivable application [10]. A brief survey of a few literary works here is introduced under here.

Literature Review

Ali M.Rashidi and M.Moshrefi-Torbati [5] have explored the impact of treating conditions on the mechanical properties of ductile iron with double framework structure. Tempering is the most vital heat treatment transform that was connected to extinguished steel & cast iron. The targets of this procedure incorporate decreases the brittleness of the material, change of toughness and ductility and decreases the cracking probability. The materials have that arrangement for dissected the properties of test 3.56% C, 1.94% Si, 1.33%Ni, 0.28 %Mn, 0.29% Mo, 0.017%P, 0.012%S. Keeping in mind locate a complete ferrite structure, the specimen were first heat treatment in austenazing temperature at 950°C for 2 hrs. The examples were tempered at 300°C, 400°C, 450°C, 500°C, 600°C for 1 hrs furthermore at 500°C for 30, 90,120, 150 and 180 min. after heat treatment diverse mechanical properties investigated. It was seen that by expanding the tempering temperature, there was an ascent in elongation rate, past to the sudden rebound that happened inside of the ranges of 400-500 °C, trailed by a moderate & progressive increment of elongation. Consequently, if the point is to accomplish high ductility & toughness, the double stage pliable iron with ferrite-martensite network structure ought to be tempered at temperature higher than 500°C.Again as the tempering temperature expanded, the yield quality extreme elasticity at first reduced then inside of the scope of 400-500°C remained generally consistent and afterward there was an ascent in extension rate for treating up to 120 min before it is at long last dropped. The purpose behind this impoverishment was liable to be because of a phenomena called temper embitterment. Inside of the temperature scope of 400-500°C, both quality and yield anxiety diminish .Longer length of time of treating period at 500°C expands the extension rate for treating period up to 120 min lessens quality and yield stress, from that point, they both go up once more. For any mix of temperature of treating and treating period and of up to 120 min. the measure of extreme rigidity can attractively be gotten from the expert bend's quality tempering parameter.

N.Fatahalla, S.bahi, are studied the metallurgical parameter, mechanical properties & machinability of ductile cast iron. The material composition is 80% pig iron with 39% C & 0.9% Si, remaining 20% was returned S.G. iron with 3.6%C, 2.4%Si & 0.05%Mg. The chemical analysis has been done, for this material was melted in a high frequency induction furnace. The liquid metal was treated by Fe-Si-Mg alloy (45, 50 &5 mass %, 1.6% by wt% of charge) having a grain size from 15 to 50 mm using a ladle sandwhich technique, then melt was inoculated by using Fe-Si alloy(20&80% by wt).Then ferritic heat treatment was performed using Gallen-Humb muffle furnace with maximum temperature of 1100°C.They got that the nodule size ranged from 233 to 1368 nodule/mm2 for largest diameter in sand mould & smallest diameter in metal mould ingot. Nodularity> 90% .The hardness test was also done by using Vickers hardness was found decreasing with increasing ingot diameter. There was a monotonic increase in ductility & decrease in strength was observed to occur with increase in ingot diameter. Tool life increases with increasing ingot diameter sand and metal moulds. Heat treated ingots both sand and mould have costant hardness. The tool life has changed due to variation of nodule characteristics.

H.Morrogh., studied the influence of copper in ductile cast iron. He found that Cu appears to create the noduler iron more sensitive to the effect of subversive elements. Up to 3%of Cu in the absence of subversive elements good noduler structures. If Ni is present in amount 5-20% with the presence of subversive elements then the cupper which is tolerated in presence of subversive elements can be increased, & the harmful effect of Cu can be neutralized by the addition of Ce. The mechanical properties noduler cast iron increased if the amount of Cu is increased upto a certain level. The noduler iron which has no Cu had a matrix of 95% ferrite and 5% pearlite. The iron which has 0.27% of Cu had 50% ferrite and 50 % pearlitic structure. 3% Cu had no harmful effects on the noduler graphite formation. The cast iron which has 0.04% Ti without Cu has almost graphite structure with trace of a flake form of graphite in matrix of pearlite. Ti gives the small amount of flake form of graphite in a matrix of pearlite with spherulitic nodules. The presence of 0.04% Ti with 1 % Cu is sufficient to interfere with the formation of noduler graphite. For Cu base alloy containing 25-40% magnesium and 1-6% Cerium is used to avoid from danger of Cu addition.

Mahmud Hafiz [26], studied the mechanical properties of spheroidal graphite (SG)-iron subjected to variable and isothermal austempering temperatures heat treatment. Variable austempering temperature heat treatment is carried out by austenitizing at 1183 K then quenching into a salt bath held at 593 and 723 K, respectively. After quenching, the former is steadily heated to 723 K while the latter is allowed to cool progressively to 593 K. The tensile properties, impact toughness and hardness are determined and correlated with the microstructure. Chemical composition of samples was C 3.5%, Si 2.54%, Cu 0.018%, S and P 0.007% and rest was Fe. The microstructure of the as-cast SG-iron is typical bull's eye structure. This structure has a non-homogeneous matrix due to the presence of varying amounts of ferrite and pearlite. Consequently, total combined carbon in the matrix is not uniform throughout the matrix. To get auniform matrix structure, SG-iron is annealed and the resulting matrix structure is fully ferritic two groups of experiments have been carried out for this. In the first one, specimens are austenitized at 1183 K for 3.6 ks, then austempered at constant temperatures namely 593 and 723K, respectively, for 5.4 ks followed by cooling in still air to 300 K.

The microstructure study shows the at austempering temperature 593° K very fine needles of ferrite are observed with small amount of retained austenite in between. As the temperature is raised to 723 K, the amount of austenite is increased. Increasing the austempering temperature is also found to result in coarse ferritic needles ferrite isolated from each other by austenite-regions the microstructure in that case consists of a mixture of upper and lower ausferrite. In the specimens quenched from austenitizing temperature of 1183 to 723 K and cooled progressively over a 3.6 ks period to 593K have a microstructure consists of widely spaced ferrite and retained austenite. The microstructure of specimens quenched from 1183 K into a salt bath held at 593 K and heated to 723 K over a 2.7 ks .This structure contains a mixture of lower and upper ausferrite. The tensile properties of specimens quenched at 593 K and heated steadily to 723 K, have higher 0.2% yield stress and ultimate tensile strength but much less ductility than those quenched at 723 K and cooled progressively to 593 K. It can also be noted that the 0.2% yield stress and the ultimate tensile strength are slightly lower than those of specimens quenched at the same temperature but isothermally held for 5.4 ks. However the elongation of the former is about Three times of the latter. While specimens quenched at 723 K and steadily cooled to 593 K showed a 0.2% yield stress and an ultimate tensile strength slightly lower than those of specimens quenched and isothermally austempered at 723 K. However, the elongation is almost the same under both austempering conditions. the specimens quenched at 593 K and heated steadily to 723 K display higher impact toughness than those quenched at 723 K and cooled progressively to 593 K. the hardness of specimens quenched at 593 K and steadily heated to 723 K is lower than that quenched at the same temperature and austempered isothermally. The fracture surfaces off different heat treated samples were investigated also. Specimen austempered isothermally at 593K for 5.4 ks, shallow dimples and cleavage fracture pattern could be observed. On the other hand, fine dimples and less areas of cleavage fracture are the characteristics of specimen's austempered isothermally at 723 K for 5.4ks. The fracture surface of specimen quenched at 593K and heated progressively to 723 K shows fine dimples near the graphite nodules and a quasi-cleavage pattern of fracture in areas far from the graphite nodules. A wide and deep dimple pattern of fracture reflecting the high ductility and toughness of the The specimen quenched at 723 K and cooled steadily to 593 K.

A. S.M.A. Haseeb et.al.[35], compared the tribological behavior of quenched, tempered and austempered ductile iron at the same hardness level (445KHN). The chemical composition of ductile iron was 3.6%C, 2.5% Si, 0.6% Mn, 0.01% S and 0.02% P and balance Fe. For the heat treatment all the samples were austenitize at 860°C then quenching was done in brine and tempered at 350°C.For austempering austentizes samples were transferred quickly to a lead bath maintained at 350°C. The samples were kept in the lead bath for 2 min, after which they were allowed to cool in still air for attaining the same hardness level. They found that wear rate increases with the increase of sliding distance. The rate of increase is higher during the initial (running-in) period. After a sliding distance of $2*10^3$ m the wear rate attains a steady state value. The wear rate of austempered ductile iron is always lower than that of the quenched and tempered ductile iron. The rate of increase of wear rate as a function of load is much higher in the case of quenched and tempered samples than in austempered samples. Comparison of two samples show that the wear resistance of austempered iron is better than that of quenched and tempered iron at longer sliding distances. The morphology of the wear scars on quenched and

Tempered, and austempered ductile iron shows that in both cases scars show a similar morphology. These sliding marks running more or less parallel to each other are seen on the micrographs. The dark patches are thought to represent oxidized surface. The quenched and tempered samples show a decreased hardness below the worn surface while an increase in hardness is observed in the case of austempered samples. The difference between the wear resistance of quenched and tempered, and austempered ductile irons both having the same initial hardness can be related to the difference in their microstructures. Metallography and XRD reveal that the microstructure of quenched and tempered iron consists mainly of tempered martensite. XRD has revealed that austempered ductile iron used in the present study contains 23% retained austenite. However, the XRD pattern of the worn surface recorded after the wear test does not show any retained austenite peaks, indicating that during the wear process, retained austenite has been transformed and this transformation was martenstic transformation. So, under an applied stress resulting in an increase of hardness.

CHAPTER 3:

3.1 Properties of ductile cast iron.

Mechanical properties of ductile cast iron is very important. With the help of properties we know about materials properties and its application. We consider that types of material to be used for industrial applications which have perfect mechanical properties and with very economical. During mechanical properties takes into account hardness, tensile strength, elongation, elastic modulus, impact and fatigue strength, conductivity and machinability, physical properties include damping capacity,. The material to be used should be capable to survive under the service conditions without any risk. Which can be determined by its corrosion resistance wear resistance, heat resistance.

Different types of mechanical properties of ductile cast iron:-

Tensile strength: Ductile iron has greater tensile strength mostly ranging between from 414Mpa for ferritic grades of ductile iron and for martensitic or austempered ductile iron have 1380Mpa.

Yield strength: Yield strength is that stress at which the materials initiates to plastic deformation. Ductile irons mostly have 0.2% yield strength. Yield strength of ferritic grades of ductile iron have ranges from 275Mpa and martensitic grades of ductile iron have ranges from. 620Mpa

Ductility: Ductility is very important properties in cast iron. Austempered ductile irons have the highest combination of strength and ductility properties. If the materials have more elongation properties then it can't break easily that types of materials have good strength and toughness.

Modulus of elasticity: Modulus of elasticity of ductile iron ranges from 162-170Gpa.

Ductile irons have a proportional stress-strain limit which is similar to the steels but is hampered by plastic deformation.

Easy to cast: If materials have High fluidity then its enables to be easily casted.

Excellent corrosion resistance: Ductile irons have excellent corrosion resistance.

Machinability: Ductile iron have also excellent machinability due the presence of graphite which is available in free form with softer phase. Therefor chip formation is easier in ductile iron.

Cost per unit strength: Ductile iron have very lower cost than other materials. Therefor its wide range of applications in manufacture industry.

3.2 Effect of alloying elements on the mechanical properties.

1): **Silicon:** Adding of the Si in the ductile iron Melton metal which is provides the ferritic matrix with pearlitic matrix. Silicon improves the properties of ductile iron at elevated temperature by stabilizing. If increasing silicon content increase the proof stress, hardness and tensile strength. Formation of ferritic matrix and silicon reach on surface layer, which is prevent the oxidation. The potentially objectionable influences of increasing silicon content are:

1). Reduced impact test energy of materials.

2). Increased impact transition temperature of the materials.

3). Decreased thermal conductivity of materials.

Si is used to developed ferrite and to strengthen ferrite. Therefor Si is mostly held below 2.2% when developing the ferritic grades and if producing pearlitic grades then Si content between 2.5% and 2.8%.

2). **Manganese:** Manganese promote the mild pearlite, for developed required properties like proof stress and hardness to a small level. Mn delays the beginning of the eutectoid transformation, therefor its decreases the rate of diffusion of Carbon in ferrite and stabilize cementite (Fe_3C) formation. But due to embrittlement formation its limiting range between 0.3 to 1%.

3). **copper:** Copper is promoter strong pearlite formation. It increases the tensile Strength with also proof stress and hardness with no embrittlement in matrix phase. Therefor for formation pearlitic grade of the ductile Iron we used copper between ranges 0.4- 0.8% and is a contaminant in the ferritic grade.

4). **Nickel:** Nickel help to increase the ultimate tensile strength without any affected of the impact strength, therefor its added range between 0.5 to 2.0% in the metal composition to maintained the proper and perfect mechanical properties. It has much less effect on strengthens ferrite, than Silicon in reducing ductility. If nickel added more than 2% in materials than it is danger to formation of embrittlement.

5). **Molybdenum:** Molybdenum is an also slight promoter the pearlite formation. In heavy sections it Forms intercellular carbides. It Increases proof stress and hardness. There is also danger of embrittlement, it is gives low tensile strength and ductility and also improves properties at elevated temperature.

6). **Chromium:** chromium prevents the formation corrosion on the surface by forming of layer of chromium oxide and it also prevent to exposition of the surface to atmosphere.it is not required carbide free structure because it formed strong carbide.

8).**Sulphur and Phosphorus:** Amount of Phosphors in the metal kept very low, because It main reasons for cold shortness therefor ductile iron properties will be ruined. But the S is better for machinability, Sulphur amount kept very low between 0.009 to 0.015%. If larger amount of Sulphur added it may cause the red shortness.

3.3 Applications of Ductile cast iron.

Ductile iron used in many industrial application to manufacture industrial equipment as like pipe used for water and sewer lines. Its pipe are stronger and easier to tap and it requires very less support and provides Better flow area for water. It also compared with others pipe which made from other materials. Ductile iron pipe can be a Better choice than PVC, polyethylene, concrete, or steel pipe. Ductile iron is very useful in automobile industry to made several automotive parts, where strength needs better than of aluminum but do not necessarily require steel. The main industrial applications of the ductile iron on off-highway diesel trucks, agricultural tractors, and oil well pumps.

- Engine crank shaft
- Brake caliper, disc – brake anchor, brake anchor plate
- Machine – tool bed
- Electric insulator post and cap
- Steering knuckle
- Rack and pinion of steering assembly
- Piston for impact drills
- Rolling mill rolls
- Moulding boxes and mould box clamps
- Brake shoe for heavy duty brakes
- Glass moulds
- Spacer cage for rolling bearing
- Piston rings
- Wind mill items

CHAPTER 4. HEAT TREATMENT OF DUCTILE IRON

Heat treatment is a very valuable processes which can change the materials mechanical properties. The heat Treatments can be done for formation of graphite and different types of microstructure. Heat treatment is the control of microstructure and properties of materials, it allowing a high amount of ferritic and pearlitic matrix in the materials microstructure. For better mechanical properties obtain by improvement of heat treatment and different types of processes and if charge materials quality is better than the application of consistent and effective practices for melting, inoculation holding, treating, and cooling in the mold.

Following properties of ductile cast iron affected by heat treatment processes.

1. Increase toughness and ductility,
2. Increase strength and wear resistance,
3. Increase corrosion resistance,
4. Stabilize the Microstructure, to reduce growth,
5. Equalize properties in castings with widely varying section sizes,
6. Improve consistency of properties,
7. Improve machinability, and
8. Relieve internal stresses.

Different types of heat treatment processes:

1. Austenitizing
2. Tempering
3. Annealing
4. Normalizing
5. Quench Hardening
6. Austempering

4.1 Austenitizing

Austenitizing is a heat treatment process in which ferrous metal heat treated above the critical temperature for an appropriately time that matrix of the materials fully transformed to austenite. For produce a uniform matrix austenitizing temperature take before any heat treatment process. The carbon content in the austenite phase is define by presence of silicon content at in the austenitizing temperature. Time and Austenitizing temperature both are depend on the formation of microstructure and composition of material. Austenitizing temperatures in the range (900-950^{o}C) are normally used in the heat treatment, with times ranging from 1h to 3h. If high amount of silicon presence in the ductile iron then high nodule count, decrease breakdown times, carbide stabilizers are presence as like chromium, vanadium and molybdenum required significantly more times for nodule count. At lower temperatures pearlite decomposed rapidly than carbide breakdown. This types of breakdown is improve by high amount of silicon and high nodularity and underdeveloped by pearlite stabilizing elements such as copper, Manganese, tin, antimony, and arsenic. Manganese and chromium both separated in to cell boundaries for incomplete dissolution of both carbides and pearlite and to prevent mechanical properties to damage.

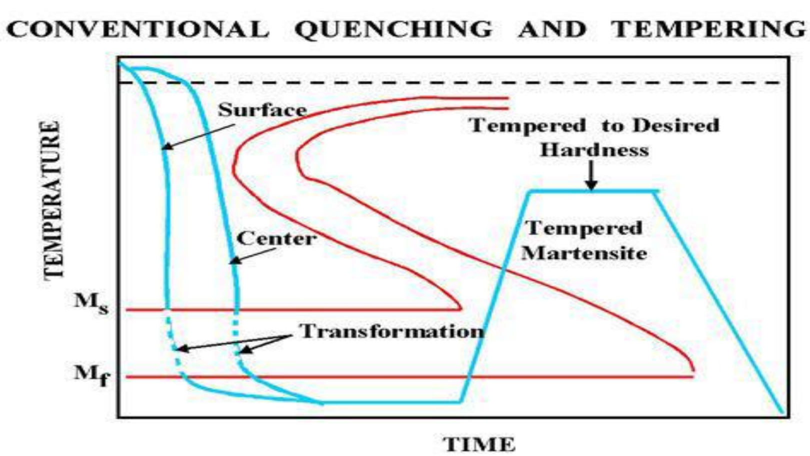


Figure 4.1: Conventional Quench & Tempering Process

4.2 Tempering

Tempering processes is the heat treatment processes in which the normalized ferrous alloy or Quench-hardened is Re-heated below the transformation temperature and cooling is done at any as requirement. Tempering heat treatment processes is relieve thermal residual stresses and also Improving ductility and toughness.

Tempering heat treatment results in:

1. Decreases brittleness of the materials
2. Improving ductility and Toughness
3. Decreases Hardness and Strength

4.3 Annealing

`Annealing procedures from a low temperature anneals with used of ferritic and carbide free castings, and other Second-stage at high temperature anneals designed to break down carbides. The main purpose of annealing is to form ferritizing.

4.5 Quench Hardening

Maximum hardness obtained in ductile cast iron by austenitizing, quenching heat treatment processes with proper time and it reduced the formation of ferrite and pearlite and developed a metastable austenitic phase which transformed to martensite at lower temperature. Hardness of the materials is depends on amount of the carbon content and it form the martensite and the volume fraction of martensite in the matrix. The finest carbon content and maximum hardness is abtained in Austenitizing temperature of (900ºC). But low carbon austenitic phase developed at lower temperatures, (800-845ºC), and after cooling it produced softer martensitic phase. Low carbon contained martensite phase will reduced distortion and cracking in complex shape castings deigned during quenching. At tempered heat treatment processes, low carbon martensite has larger toughness than the both tempered high carbon martensite and normalized microstructures.

Higher austenitizing temperatures increase the carbon content of the austenite but the bulk hardness is reduced due to retained austenite and a lower resultant martensite content. Quenched Ductile Iron castings must be tempered before use to eliminate internal stresses, control strength and hardness and provide acceptable ductility.

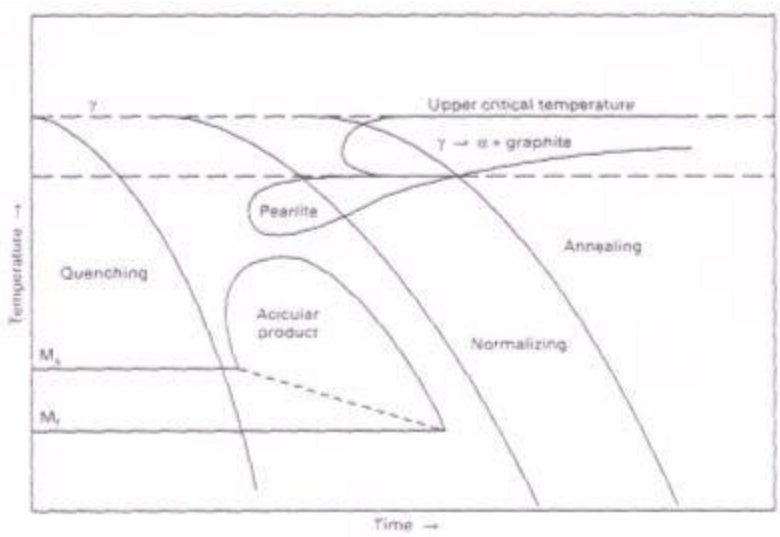


Fig 4.2: CCT diagram showing annealing, normalizing and quenching

Ms stand martensite start, Mf for martensite finish.

CHAPTER 5. EXPERIMENTAL PROCEDURE

5.1 Specimen preparation.

Chemical compositions of the material are given in Table 5.1

Table 5.1 Chemical composition of specimens in wt. %

Elements	Wt. %
C	3.52
Si	2.04
Mn	0.17
S	0.008
Mg	0.042
P	0.024
Cr	0.02
Ni	0.15
Mo	0.001
Cu	0.02
Ce	0.007
Fe	Balance

I have 6 pieces of specimen, each have a specific size according to ASTM standards. The every specimen have same gauge length but Width & thickness in measurement is according to fig.5.1.

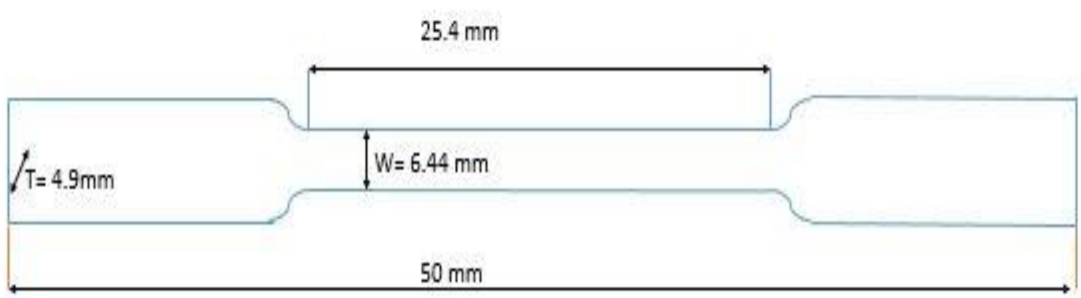


Figure 5.1: Specimen Specifications

In order to investigate the structure-property relationship, ductile iron test blocks with different alloying elements were brought from L&T Kansbahal, India. The chemical composition of test block by weight percentage is presented in Table 5.1. In order to carry out the experiment specimens were machined from the test blocks.

5.2 Heat treatment.

The various heat-treatments processes for our study were:

1. Austenitising

2. Quenching

3. Tempering

Austenitising

By using induction furnace for austempering process of all sample were heated in austeniging temperature at 900°C for 120 minutes. After 120 minutes stop the furnace and quickly transferred the all sample in to the salt bath or mineral oil at room temperature.

Quenching

All sample was quenched in mineral oil at room temperature up to 15 minutes. after quenching Immediately tempering heat treatment processes was done of three sample at 400°C and remaining three at 200°C for different times 60 min, 90 min, and 120 min respectively.

Tempering

1) All the three sample tempered in the furnace and rise the temperature up to 400°C then sample was kept on 400°C temperature up to 60 min, 90 min, and 120 min, respectively.
2) Then remaining all three sample again tempered in the furnace and rise the temperature up to 200°C then sample was kept on 200°C temperature up to 60 min, 90 min, 120 min, respectively.

After heat treatment oxide layer from each of the specimen was removed by conventional filing & emery paper polishing and cloth and diamond polishing method.

5.3 Tensile strength

Tensile test were carried out according to ASTM (E8 370-2002) Test were conducted by using Instron 1195 universal testing machine connected to computer to draw the stress-strain curve accounting to tensile strength, tensile load of 50KN applied to the specimen up to the breaking point. Specimen have specific measurement of each sample. After failure we obtained tensile strength of different sample and stress-strain curve at different time and temperature. After tensile test we cut the small fracture surface part very carefully to investigate the brittle and ductile behavior by using SEM (Scanning Electron Microscope).

Fractography: Fracture surface of the sample after tensile test are analyzed by scanning Electron microscopy (SEM). First cleaned with acetone and properly handle, so that the fracture surface does not get damaged. Thereafter the specimen is cut to appropriate size for analysis using SEM (Scanning Electron Microscope.) Then all the specimens are kept under SEM for analysis of fracture surface. A series of photographs are taken in due course of experiment which helps in determining the type of fracture that has taken place.

5.4 Polishing & Etching.

After tensile test cut the small fracture surface and remaining part of sample use to investigate the microstructure of materials by using grinding machine. Then all Specimens were first polished with belt polisher then followed by 1/0, 2/0, 3/0, 4/0 grades of emery paper and given a sufficient time for each paper and after paper polishing cloth polishing was done with using alumina slurry followed and finally diamond polishing done. Then etched 2% nital. But after polishing takes microstructure before etching for investigate the number of nodules and nodularity in each sample then we takes 10 images of each sample and using Software to investigate the nodules and nodularity.

5.5 Nodularity and Nodular count

Before etched taken metallographic images thought optical microscope and investigate number of nodules present in the 1mm² area and calculate nodularity thought the computer software. We takes 10 images of each sample before etching and by using metal power image analyzer software we investigate the nodules and nodularity. Frist we select one image and select the circular shape nodules and then remaining two phase and gives different color for each phase. Then similar remaining all images and finally investigate the threshold value of all images and after we got the number of nodules and nodularity as like given below.

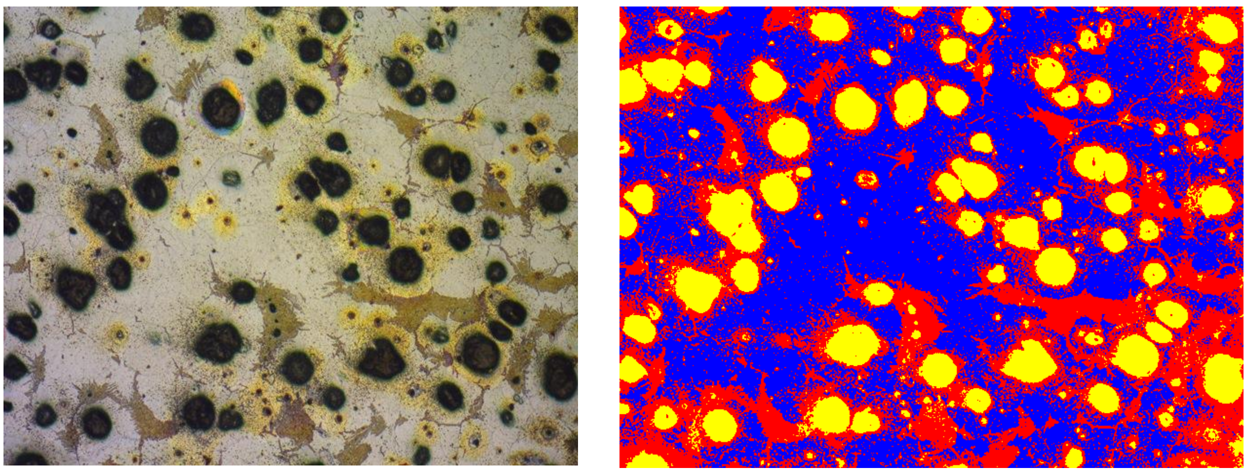
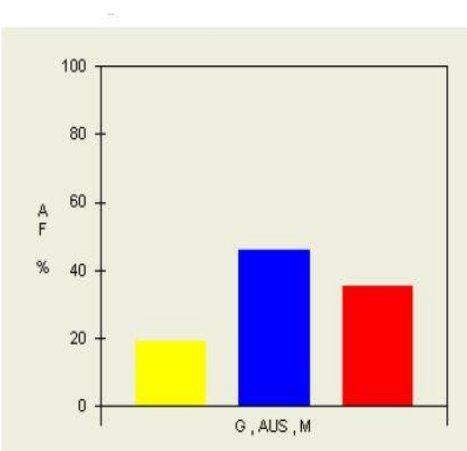


Fig.5.2: Microstructure of sample 200°C at 1h before etching and threshold value of that image



SID:200-1	Frame Area(mm²)	G(%)	AUS(%)	M(%)
Frame - 1	0.7408	19.076	43.653	37.271
Frame - 2	0.7408	19.389	47.786	32.825
Frame - 3	0.7408	20.246	43.538	36.216
Frame - 4	0.7408	18.799	46.535	34.667
Frame - 5	0.7408	19.073	46.531	34.396
Frame - 6	0.7408	18.917	47.391	33.692
Frame - 7	0.7408	18.642	46.235	35.123
Frame - 8	0.7408	17.896	46.868	35.236
Frame - 9	0.7408	19.165	43.476	37.359
Frame - 10	0.7408	17.362	46.593	36.045
Average	0.7408	18.857	45.861	35.283

Fig.5.3: Investigation report of sample 200°C at 1h by using metal power image analyzer software

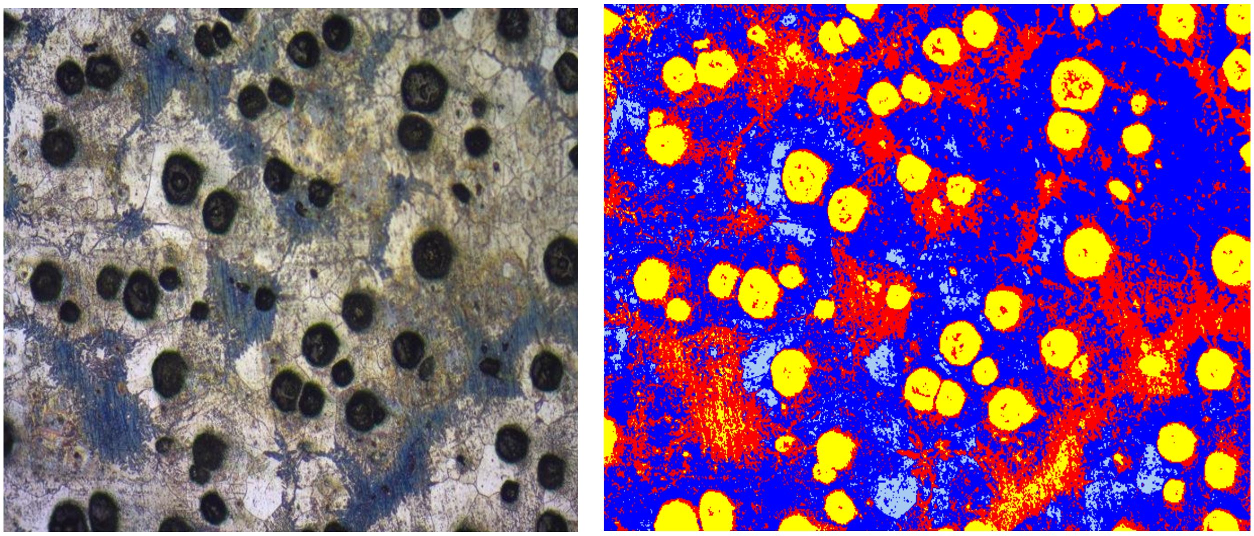
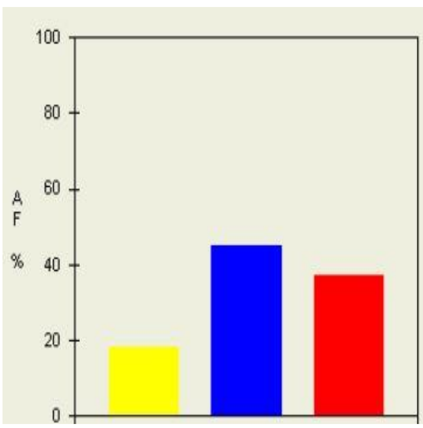


Fig.5.4: Microstructure of sample 200°C at 1.5h before etching and threshold value of that image



SID:200-2	Frame Area(mm²)	G(%)	AUS(%)	M(%)
Frame - 1	0.7408	17.164	44.950	37.886
Frame - 2	0.7408	15.626	46.281	38.094
Frame - 3	0.7408	19.043	43.995	36.962
Frame - 4	0.7408	17.540	46.199	36.261
Frame - 5	0.7408	18.863	44.323	36.814
Frame - 6	0.7408	18.604	44.445	36.951
Frame - 7	0.7408	18.257	44.976	36.766
Frame - 8	0.7408	16.412	46.342	37.245
Frame - 9	0.7408	19.402	43.750	36.847
Frame - 10	0.7408	18.184	45.024	36.792
Average	0.7408	17.909	45.029	37.062

Fig.5.5: Investigation report of sample 200°C at 1.5h by using metal power image analyzer software

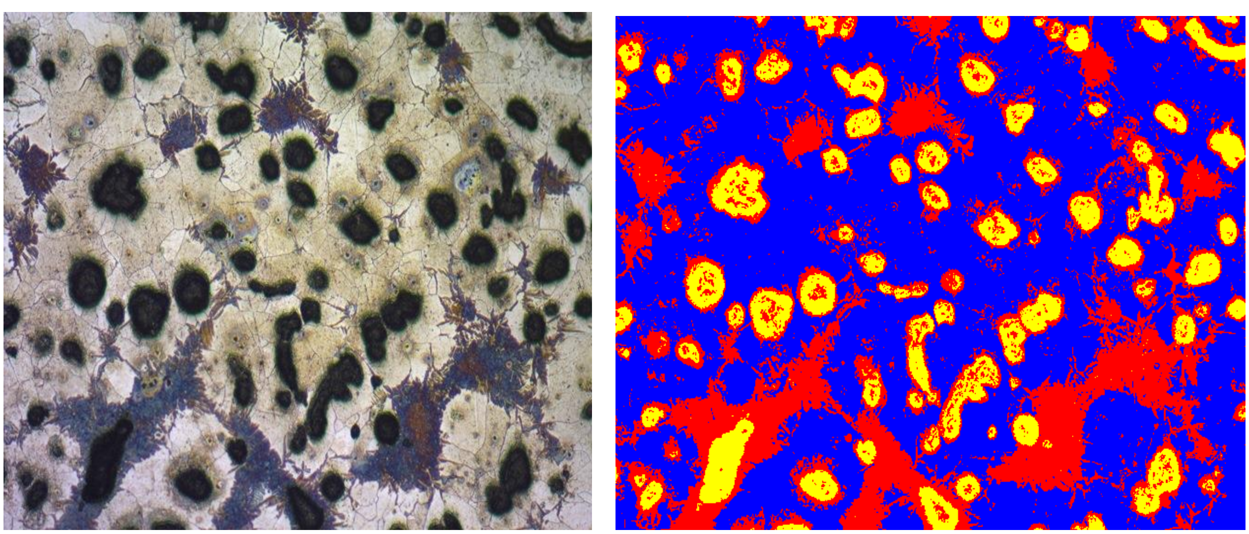
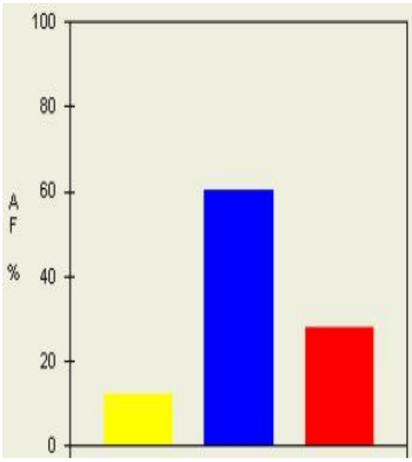


Fig.5.6: Microstructure of sample 200°C at 2h before etching and threshold value of that image



SID:200-2	Frame Area(mm²)	g(%)	aus(%)	m(%)
Frame - 1	0.7408	7.975	60.709	31.316
Frame - 2	0.7408	14.854	58.977	26.169
Frame - 3	0.7408	11.877	59.808	28.315
Frame - 4	0.7408	9.970	62.058	27.972
Frame - 5	0.7408	14.609	60.262	25.128
Frame - 6	0.7408	11.920	60.924	27.157
Frame - 7	0.7408	12.755	59.966	27.280
Frame - 8	0.7408	12.416	60.410	27.174
Frame - 9	0.7408	11.760	60.110	28.130
Frame - 10	0.7408	11.306	61.503	27.191
Average	0.7408	11.944	60.473	27.583

Fig.5.7: Investigation report of sample 200°C at 2h by using metal power image analyzer software

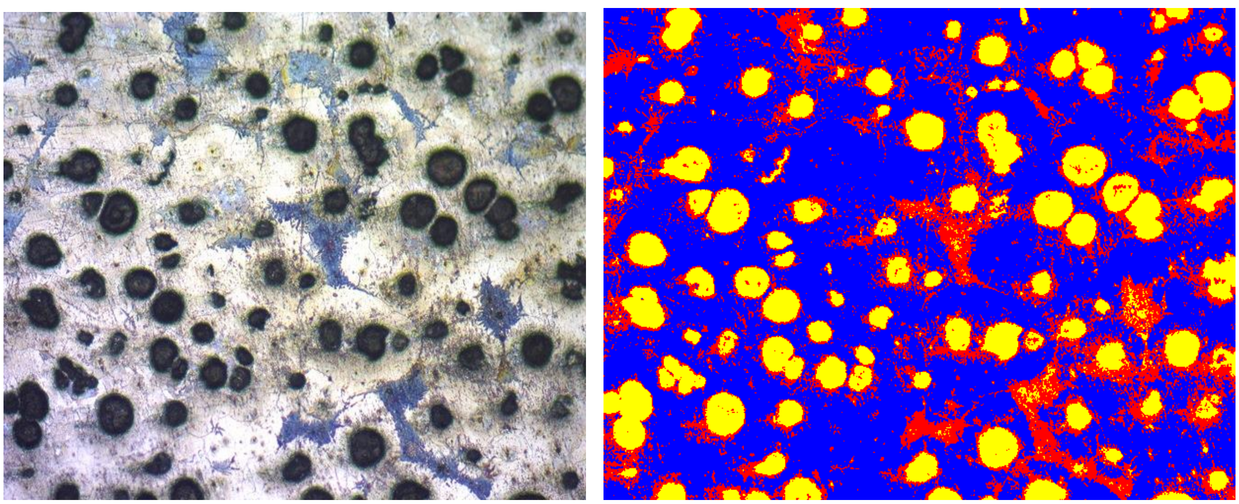
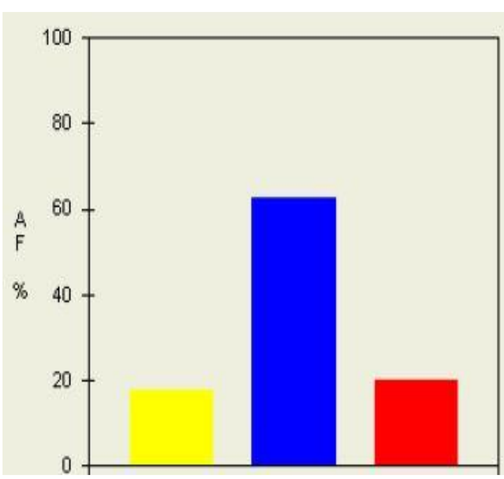


Fig.5.8: Microstructure of sample 400°C at 1h before etching and threshold value of that image



SID:400-1	Frame Area(mm²)	g(%)	aus(%)	m(%)
Frame - 1	0.7408	19.453	60.774	19.772
Frame - 2	0.7408	17.846	61.908	20.246
Frame - 3	0.7408	17.812	64.035	18.153
Frame - 4	0.7408	16.747	63.372	19.881
Frame - 5	0.7408	17.977	61.524	20.499
Frame - 6	0.7408	17.759	62.796	19.445
Frame - 7	0.7408	17.888	63.024	19.088
Frame - 8	0.7408	17.351	63.108	19.540
Frame - 9	0.7408	17.742	60.792	21.466
Frame - 10	0.7408	16.961	62.090	20.950
Average	0.7408	17.754	62.342	19.904

Fig.5.9: Investigation report of sample 400°C at 1h by using metal power image analyzer software

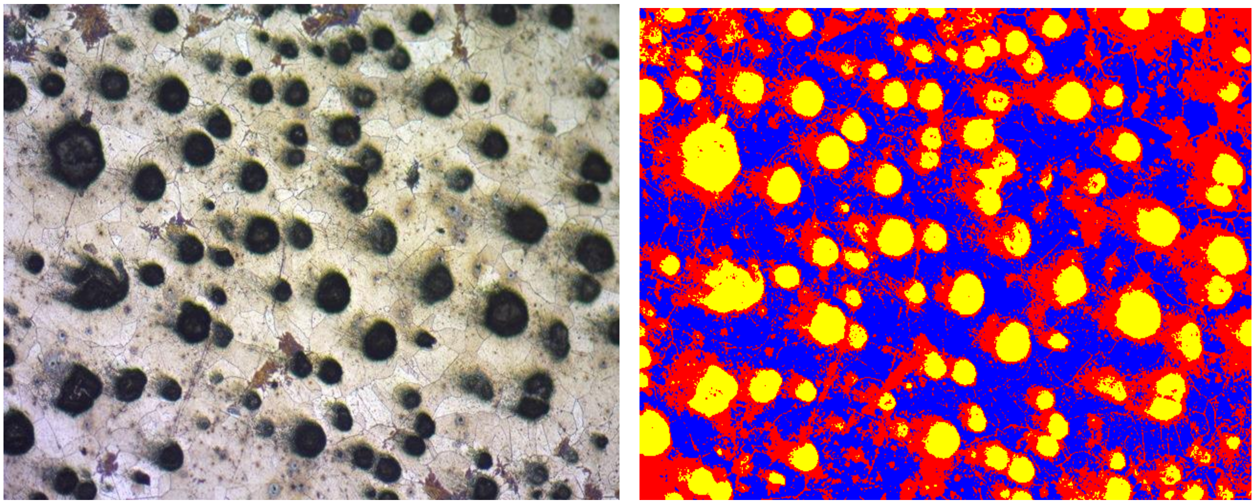
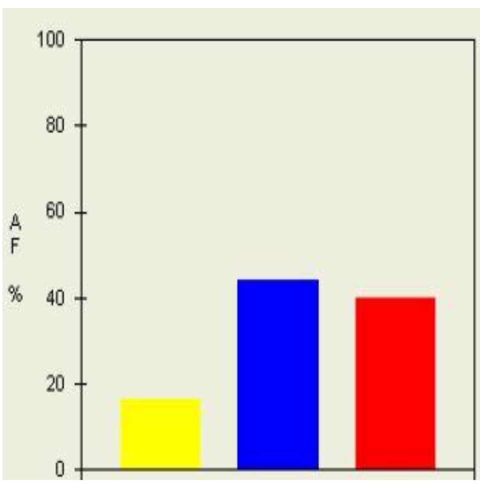


Fig.5.10: Microstructure of sample 400°C at 1.5h before etching and threshold value of that image



SID:400-1.5	Frame Area(mm²)	g(%)	aus(%)	m(%)
Frame - 1	0.7408	16.984	42.928	40.088
Frame - 2	0.7408	16.232	43.837	39.931
Frame - 3	0.7408	15.895	44.355	39.750
Frame - 4	0.7408	14.098	44.853	41.049
Frame - 5	0.7408	14.882	45.237	39.881
Frame - 6	0.7408	15.329	45.722	38.949
Frame - 7	0.7408	16.679	44.062	39.259
Frame - 8	0.7408	17.719	44.331	37.949
Frame - 9	0.7408	17.324	42.701	39.975
Frame - 10	0.7408	18.105	42.322	39.573
Average	0.7408	16.325	44.035	39.640

Fig5.11: Investigation report of sample 400°C at 1.5h by using metal power image analyzer software

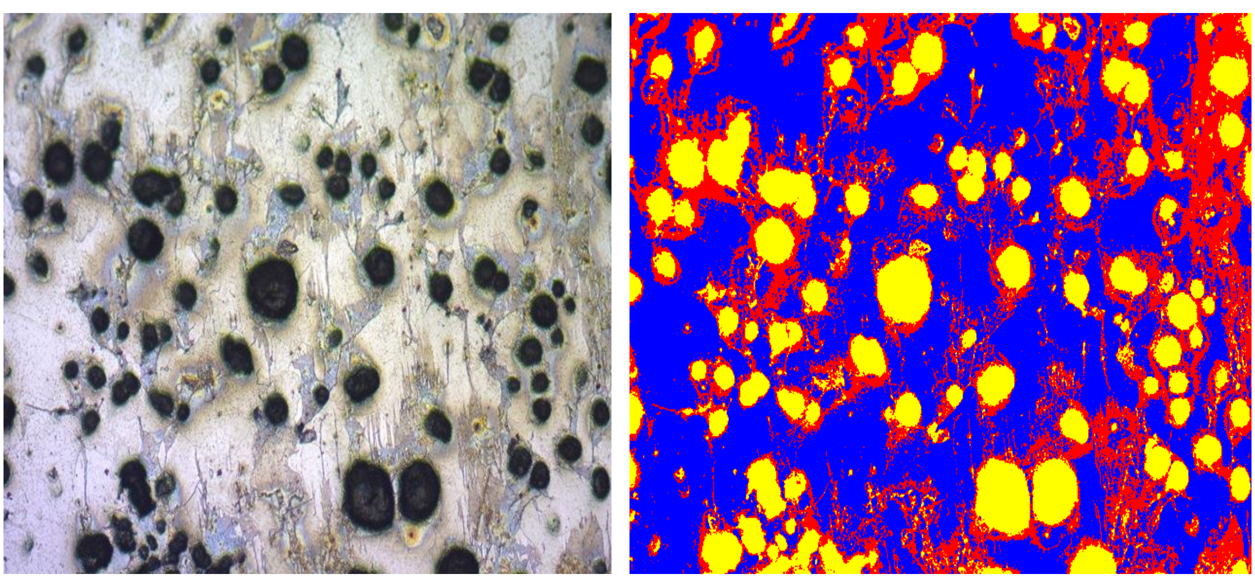
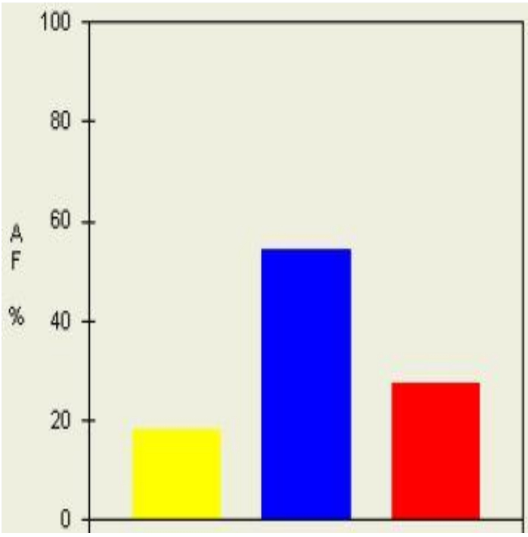


Fig.5.12: Microstructure of sample 400°C at 2h before etching and threshold value of that image



SID:400-2	Frame Area(mm²)	g(%)	aus(%)	m(%)
Frame - 1	0.7408	18.174	53.852	27.974
Frame - 2	0.7408	18.941	52.452	28.606
Frame - 3	0.7408	19.104	54.299	26.598
Frame - 4	0.7408	18.364	54.319	27.318
Frame - 5	0.7408	18.679	55.535	25.785
Frame - 6	0.7408	18.203	55.487	26.310
Frame - 7	0.7408	18.392	54.280	27.327
Frame - 8	0.7408	16.883	56.042	27.074
Frame - 9	0.7408	17.753	54.551	27.695
Frame - 10	0.7408	18.393	53.443	28.164
Average	0.7408	18.289	54.426	27.285

Fig.5.13: Investigation report of sample 400°C at 2h by using metal power image analyzer software

5.6 Microstructural study.

After investigate the nodules and nodularity we again polishing all the sample by Diamond polishing then etched 2% natal (2% conc. Nitric acid in methanol solution). Now metallographic images were taken with the help of computer integrated optical microscope at 200X magnification. We takes different Images of same sample of different places with different magnification.

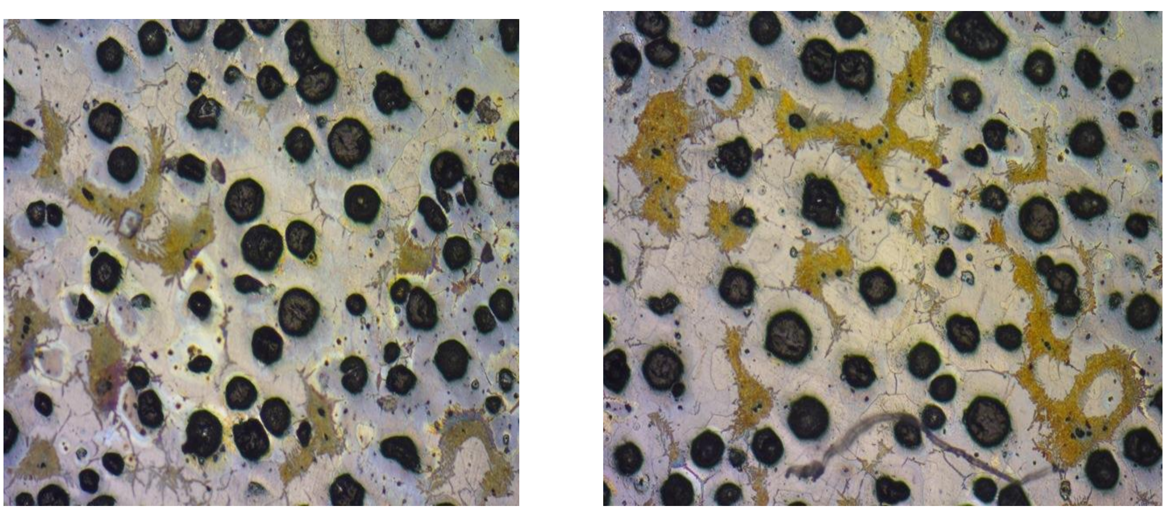


Fig 5.6: Microstructure of ductile cast iron

5.7 STUDY OF MECHANICAL PROPERTIES:

5.7.1 Hardness testing

The method utilized for hardness testing was Vickers hardness testing. Vickers hardness was measured by applying a load of 20Kg and dwell time being 10seconds on each heat treated tempered specimen. When the load was applied by Instrument on the sample. The square shape diamond indenter was penetrate the sample surface with in few 10 seconds. And by manually two diagonals, d^1 and d^2, are measured. We measure 10 different place on same sample then take averaged and the surface area calculated then divided into the load applied.

The method utilized for hardness testing was Vickers hardness testing (XHB20).

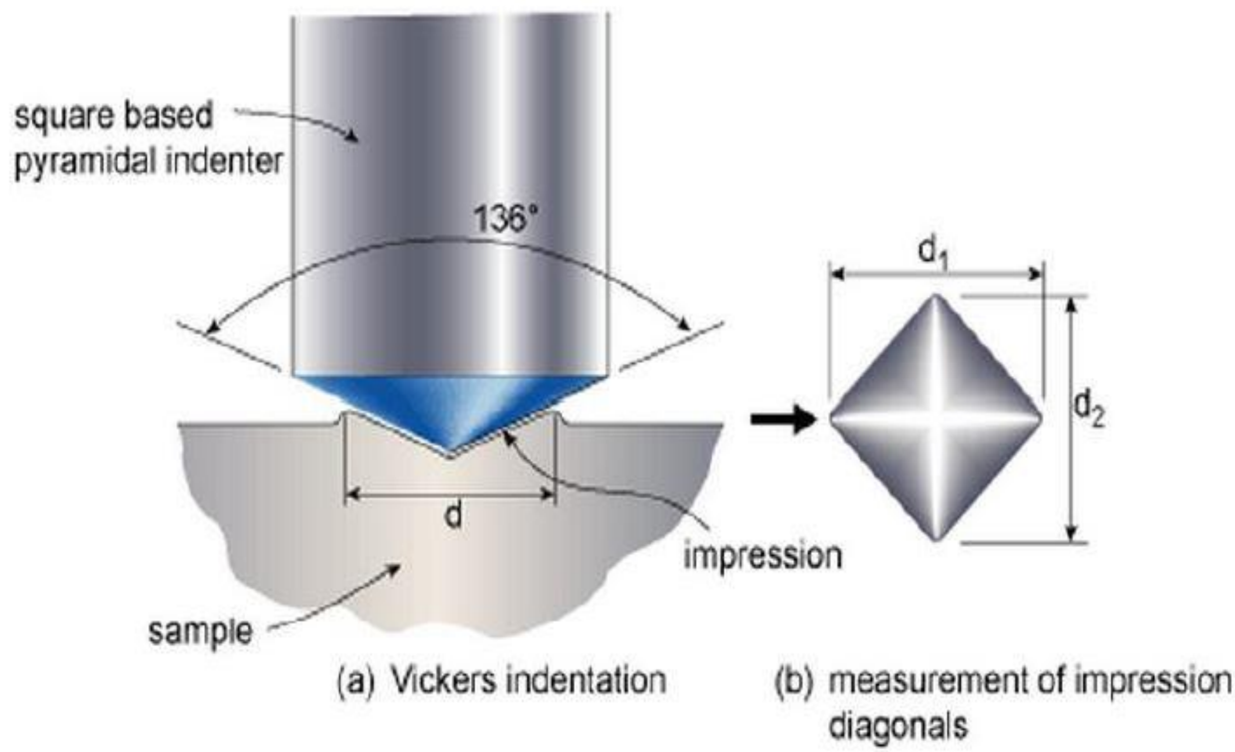


Fig.5.6.1: Measurement of hardness test by using Vickers hardness test

5.7.2 Impact testing:

Investigate the Impact energy by Charpy V-notch test and described in ASTM E23. The Charpy specimen was placed horizontally across supports with the notch away from the hammer. The indicator pointer was slide to the left until it indicates the maximum energy range on the upper Charpy- Tension scale. The pendulum arm was raised to the right until it is firmly supported by the latching mechanism. The pendulum was released by pushing up on the release knob. The hammer dropped, striking the specimen, with a swing through dependent on the amount of energy absorbed by the test specimen. The indicator moved and stopped when peak swing through was registered, providing a direct reading of the energy absorbed by the specimen. The indicated value from charpy scale was recorded.

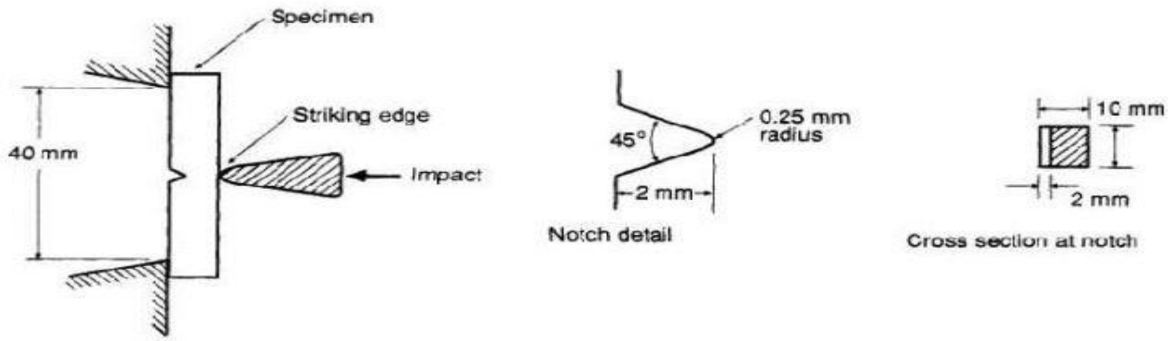


Fig.5.7.1: Charpy V-Notch Impact Testing Specimen Measurements

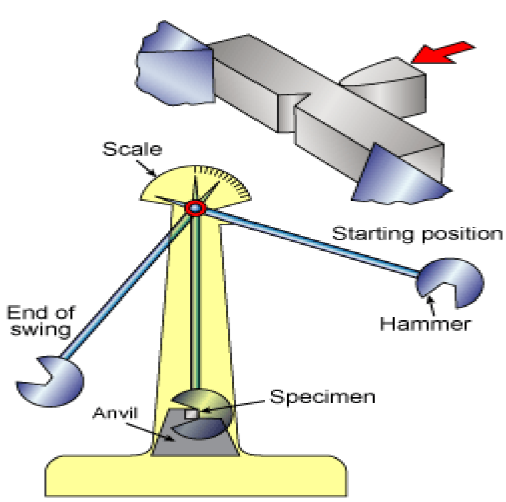


Fig5.7.2: Charpy V-Notch Impact Testing Instrument

5.7.3 Wear test:

Wear properties investigate on Ducom TR-208-M1 Ball on plate type wear monitor. Specimen was as flat plate and a spherical tipped diamond cone of 120° angle 4mm track diameter was used in order to investigate the wear system response of the different tempered specimens. The mechanism of Ball on plate wear test is very much similar to that of Pin on disc wear tester. However the minor difference is that in pin-on-disc specimen is in the form of cylindrical pin, held stationary in specimen holder and disc is the counter body which rotates against the pin, whereas in case of Ball on plate wear test instead of pin specimen is a flat one rotates against a counter ball which is fixed. Also, in pin on disc machine only the disc rotates whereas in Ball on plate mechanism both the specimen and indenter rotate at same relative speed. The Ducom TR-208-M1 Ball on plate type wear monitor along with schematic diagram of pin on disc wear monitor is presented in Fig. 1 (a) and Fig. 1 (b) respectively. Test was conducted at 20N loads for a sliding distance of 7.54m at a constant speed 10rpm with three different wear time 10min, 20min, 30min, respectively on each tempered sample. The weight loss for corresponding specimens was measured with the help of electronic balance of 0.1mg accuracy. With the help of electronic data plot graph to investigate the wear properties.

Fig.5.7.3 (a) Ducom TR-208-M1 Ball on plate type wear monitor

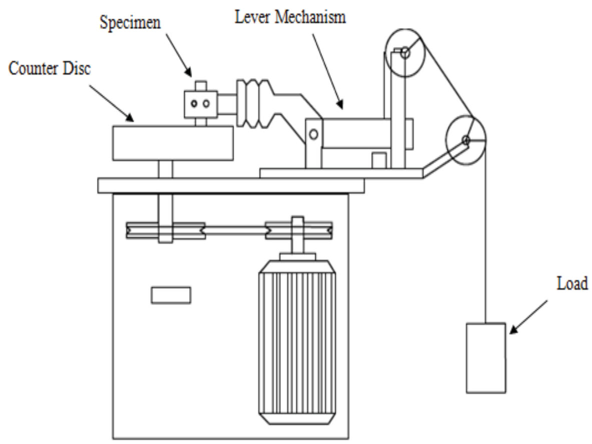


Fig.5.7.3: (b) Schematic diagram of pin on disc wear test machine

5.8:- Study of the X-Ray Diffraction:

The X-Ray diffraction (XRD) analysis was done for tempered samples. This method was used to approximation the volume fractions of retained austenite, ferrite, martensite, of matrix in the material after treatment. XRD was performed 40 KV and 40 mA using a Cu- Kα target diffractometer. Scanning was done in angular range 2θ from 40° to 90° at a Scanning speed of 10°/min. The profile were analyzed on computer by using X' Pert High Score and JCPDS Software to obtain the peak position and integrated intensities of the {101}{2 0 0}{211} plane of BCC of martensite at 200°C and other 400°C tempered sample obtained ferrite and {111},{220},{311} planes of FCC austenite. By comparing these intensities the volume fractions of retained austenite and ferrite were estimated.

6: Result and Discussion:-

The mechanical properties measured by using Instron 1195 and Dimensions of specimen was taken according to ASTM (E8 370-2002), The effects of tempering temperature on the yield stress, ultimate tensile strength, impact strength and elongation percentage are demonstrated in table 6.1, and figure 1 . The tensile properties vary with the matrix phase. In tempered martensitic and also retained austenite effected the mechanical properties, [3] when tempering time increase retained decrease and reduces the probability of cracking. and ductility again increase with time the increase in strength initially at low time interval is due to the high amount of martensite and unreacted austenite, but the time increase above 30 Minutes the stage reaction in the intercellular regions for which strength decreases and ductility increases In figure 1, Elongation of sample increases with increasing time and yield strength, tensile strength decreases with the increase in tempering time, and impact strength increases in tempering process because of increase in the toughness of the sample. Hardness decrease as the tempering temperature and time will increase. This is due to transformation of martensitic to Austenite phase, and Austenite phase in softer then the martensitic phase show in table 6.2 and figure 2.

Table 6.1. Mechanical properties of tempered specimen at 200°C and 400°C at different time

Tempered sample	**0.2% Y.S. (MPa)**	**Tensile strength (MPa)**	**% Elongation**	**Impact strength (J/Cm²)**	**Hardness**
200°C At 60 Min	**216.6**	**600.5**	**9.596**	**8.808**	**380HV20**
200C At 90 Min	**149.3**	**452**	**9.920**	**10.219**	**337HV20**
200°C At 120 Min	**145.1**	**410**	**13.210**	**11.337**	**321HV20**
400°C At 60 Min	**236.6**	**573.2**	**8.342**	**11.432**	**326.3HV20**
400°C At 90 Min	**223.1**	**518.4**	**10.650**	**16.559**	**278.5HV20**
400°C At 120 Min	**147.8**	**492.7**	**14.320**	**18.653**	**250.3HV20**

[11]The drop in hardness accompanying secondary graphitization produces a corresponding reduction in tensile and fatigue strength as well. [11] Because alloy content affects the rate of secondary graphitization, each alloy will have a unique range of useful tempering temperatures. The microstructures of respective specimens were shown in Fig.2 and this microstructure have different matrix phase, [10] tempered ductile Cast Iron have nodules graphite structure and they have also austenite and martensitic phase. [12]. the nodularization amount and graphite shape have a great effect on the workability

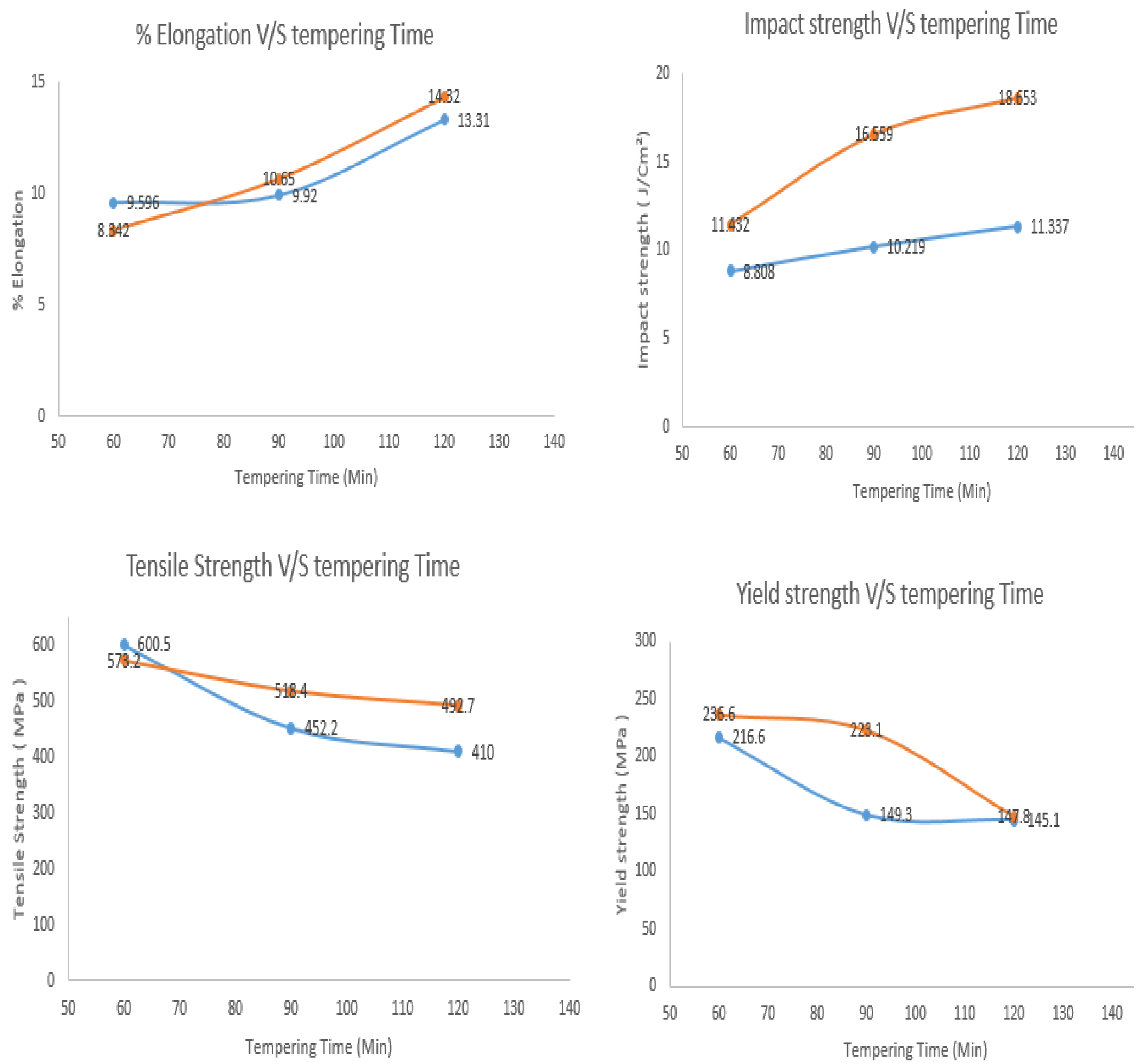


Figure.6.1: Effect of tempering Time On Elongation %, Impact Strength, Tensile Strength, Yield Strengt

In microstructures At 200°C have different amount of phase in table 3. at after austenitized temperature sample immediately quench in mineral oil at room temperature then at quenching martensitic transformation occurs and retained austenite formed ,after tempering in microstructures martensitic and retained austenite will transform into austenite and austenite phase is softer than other, that amount of matrix define the mechanical properties of ductile cast Iron.

Table 6.2. Amount of matrix presence in tempered specimen at different time and temperature

Tempering Temperature &Time	%of Martensitic	%of Austenite	% of Graphite	Nodularity
200C at 60 Min	37.062%	45.029%	17.909%	79.630
200C at 90 Min	35.283%	45.861%	18.857%	100
200c at 120 Min	27.583%	60.473%	11.944%	79.167
400C at 60 Min	39.640%	44.035%	16.325%	96.327
400C at 90 Min	27.285%	54.426%	18.289%	100
400C at 120 Min	19.904%	62.342%	17.754%	87.143

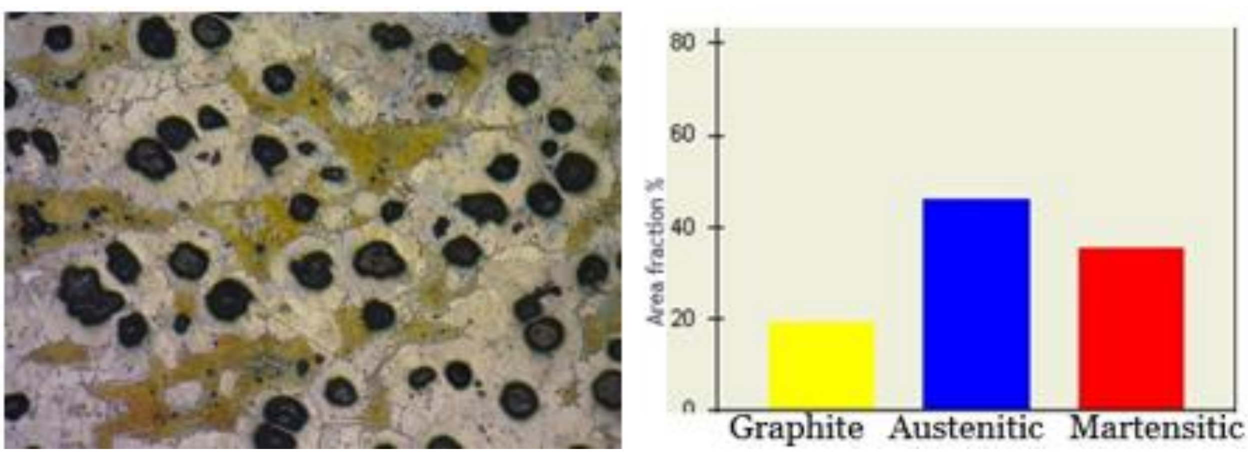


Figure 6.2:.a Microstructure of 200°C tempered specimen at 60 Min

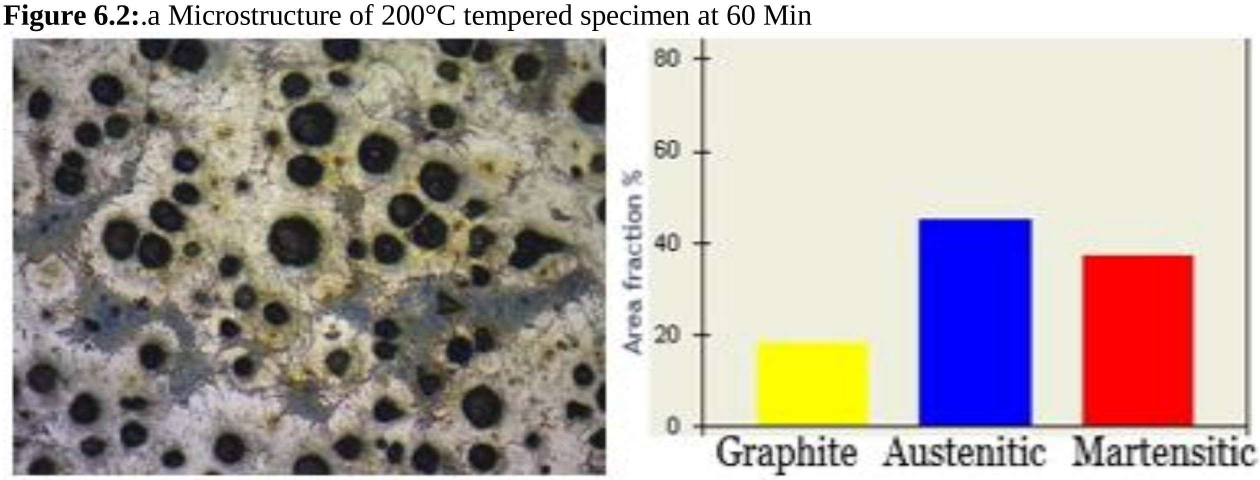


Figure 6.2: b Microstructure of 200°C tempered specimen at 60 Min

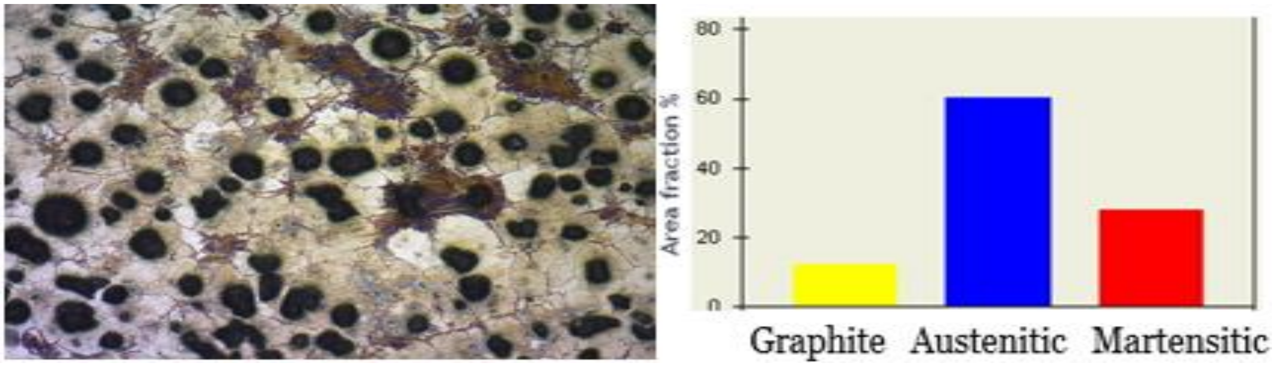


Figure 6.2: c Microstructure of 200°C tempered specimen at 60 Min

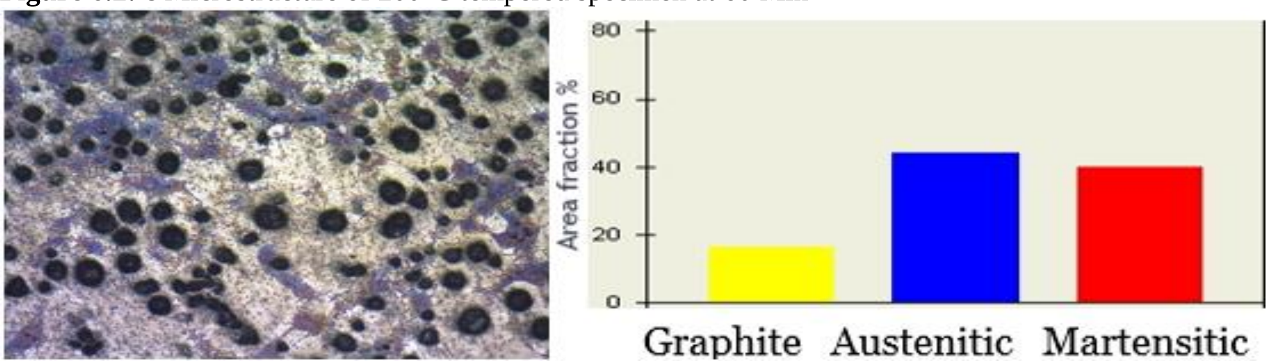


Figure 6.2: d Microstructure of 400°C tempered specimen at 60 Min

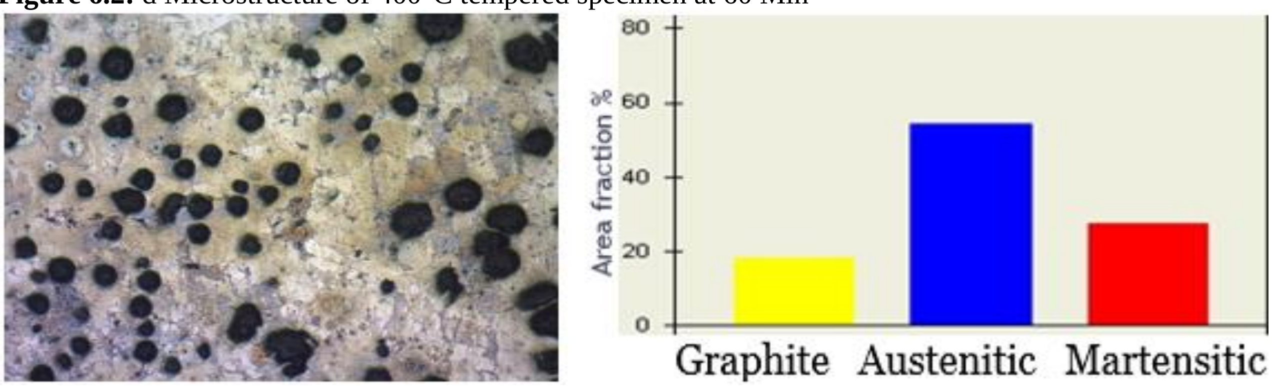


Figure 6.2: e Microstructure of 400°C tempered specimen at 90 Min

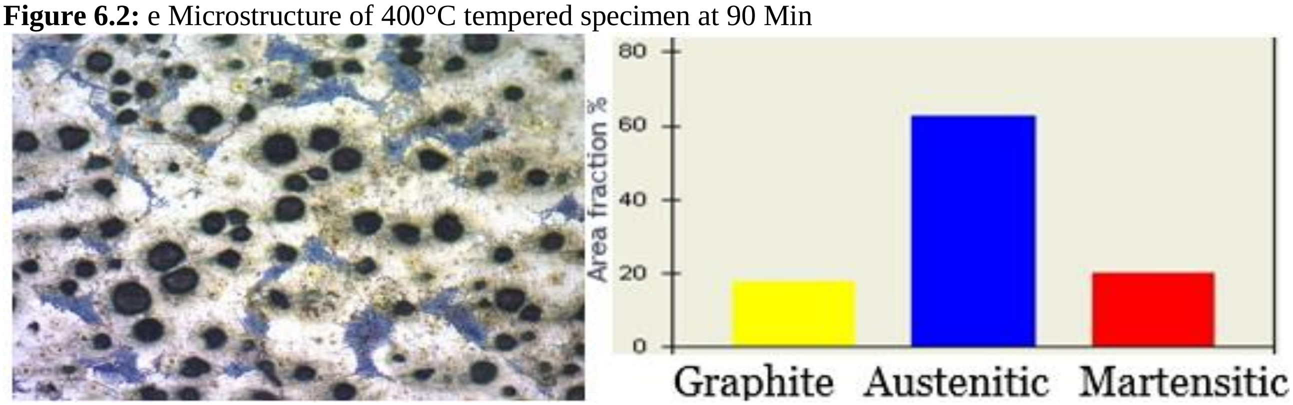
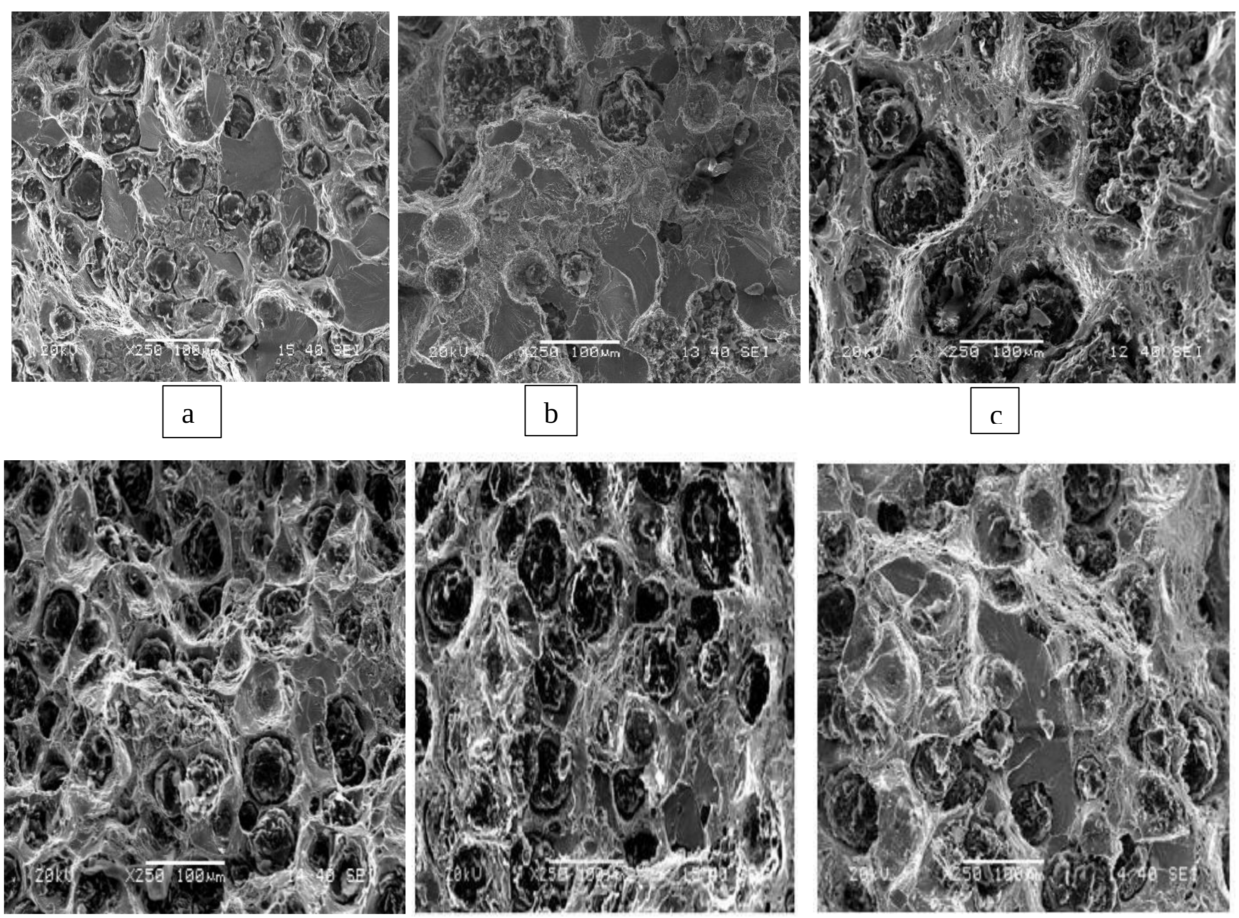


Figure 6.2: f Microstructure of 400°C tempered specimen at 120 Min

The morphology of the fracture specimens are analyzed by Scanning Electron Microscopy (SEM). Figure 3 show the fracture surface of different sample Specimens tempered at 200°C were dominant by brittle failure mode characterized by the presence flat shiny surfaces. Whereas with increase in tempering time shallow dimples were also observed in every specimens & were increased in the specimen tempered for 120 minutes. On the other hand specimens tempered at 400°C for various times showed dimples around the spherical nodules suggesting dominating nature of ductile failure mode. However the specimen tempered for 90 minutes showed mixed mode of failure characterized by presence of flat shiny surfaces along with dimples. On the other hand specimen tempered for 120 minutes showed complete ductile mode of failure.



(d) (e) (f)

Figure 6.3: Fractography Image of tempered specimen a) at 200°C in 60 min b) at 200°C in 90 min c) at 200°C in 120 min d) at 400°C in 60 min e) at 400°C in 90 min f) at 400°C in 120 min

Wear test:-

The tempered sample had the highest hardness value due to the hard martensite matrix. And when tempering time increase then hardness decreased and so as the wear depth and weight loss. At tempering temperature 400C in for 1.5hr the weight loss linear and for 1hr and 2hr weight loss differ as different tempering time with wear time as given below in a figure7.4(b). And similar at 200C tempering sample shows differ as different tempering time with wear in figure 7.4(a).

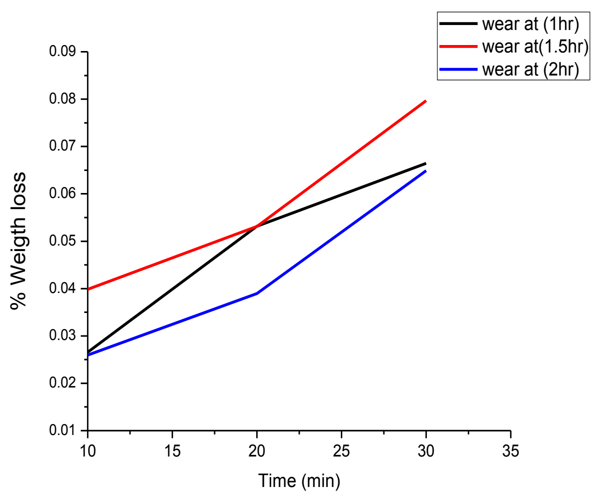


Fig.6.4: (a) % Weight Loss vs. time for Tempered sample at 200C

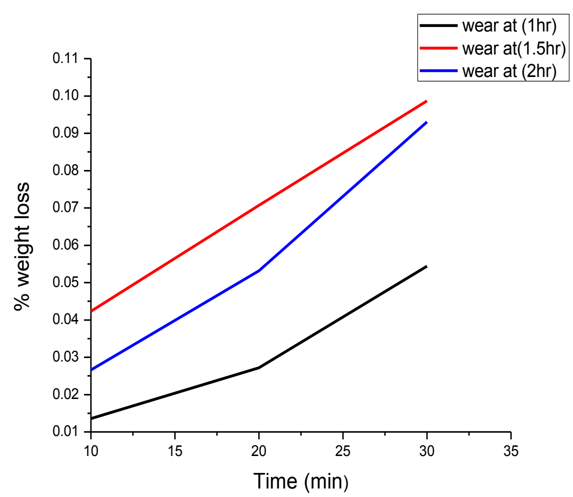
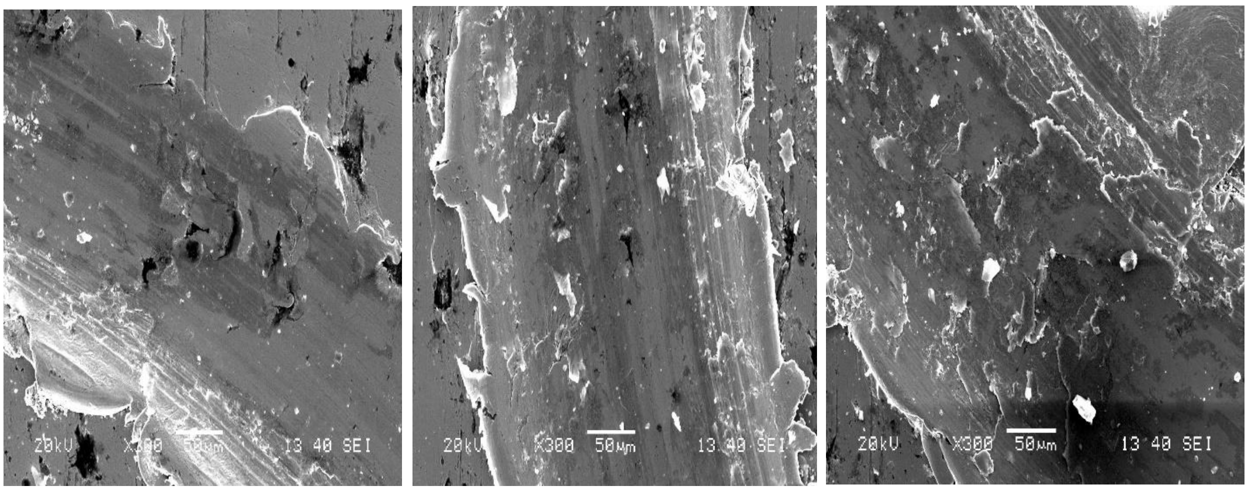


Fig.6.4: (b) % Weight Loss vs. time for tempered sample at 400C

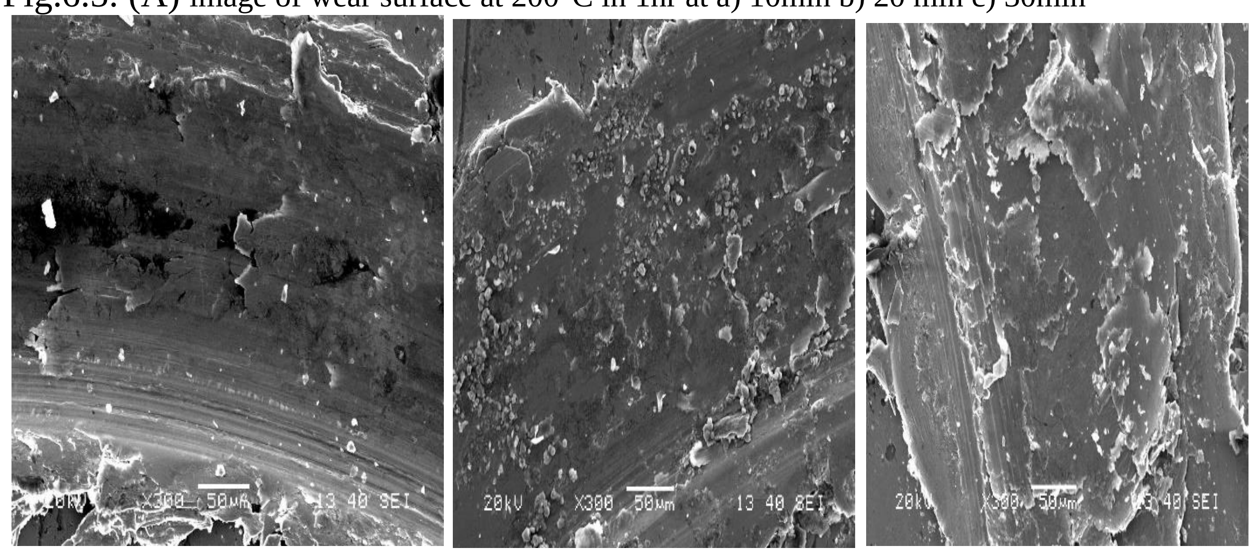
Study of the wear mechanism:

To investigate the wear mechanism of micrographs of worn surfaces of heat treated Sample were taken with the held, and presented in Fig.7.6. Direction of wear track was shown given below in each case. It was found that for the sample tempered at 200°C for 1 hours the wear is mainly caused by the delamination of the surface. At the minimum time duration of 10minutes samples presents almost smooth surface with small delamination crater. When the time increases to 20 minutes, the worn surface shows rough surfaces with significant delamination damage. On further increasing the time to 30 minutes, the wear surface shows intensively severe delamination damage and more material pull out was observed. Similar observation was made in the sample tempered at 200°C for 1.5hr and 2hr with increasing time duration. However at 200°C in 2hr at wear time 20 minutes and 30 minutes oxidation take place.



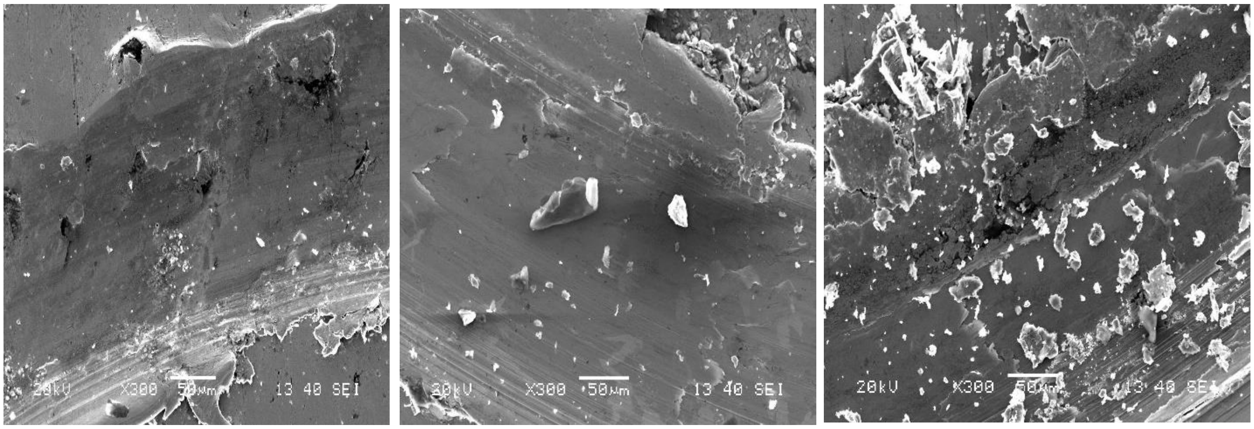
(a) (b) (c)

Fig.6.5: (A) image of wear surface at 200°C in 1hr at a) 10min b) 20 min c) 30min



(a) (b) (c)

Fig.6.5: (B) Fractography image of wear surface at 200°C in 1.5hr at a) 10min b)20 min c) 30min



(a) (b) (c)

Fig.6.5: (C) Fractography image of wear surface at 200°C in 2hr at a) 10min b) 20 min c) 30min

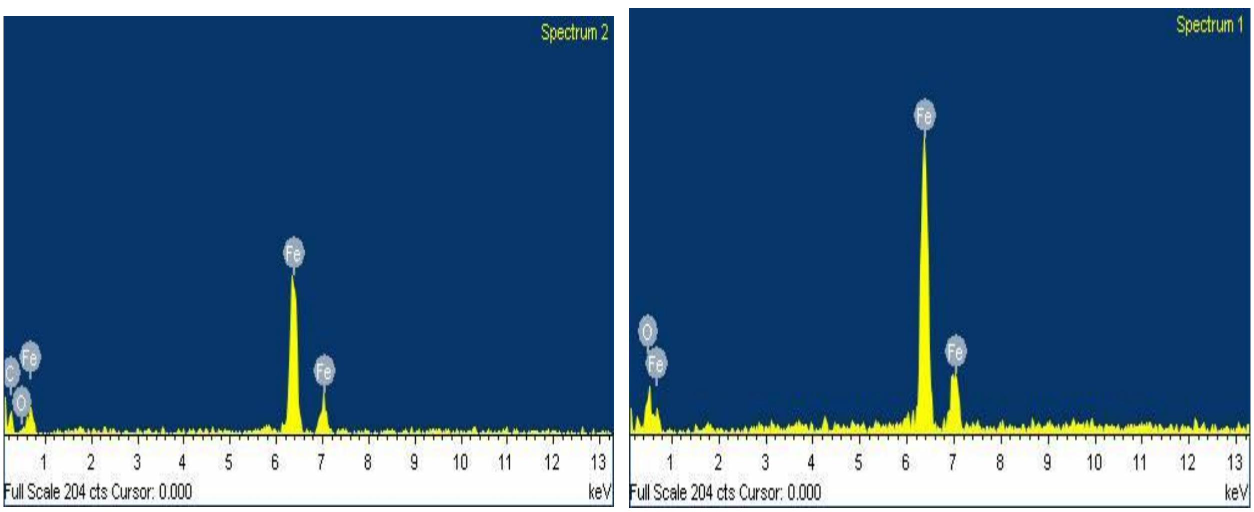
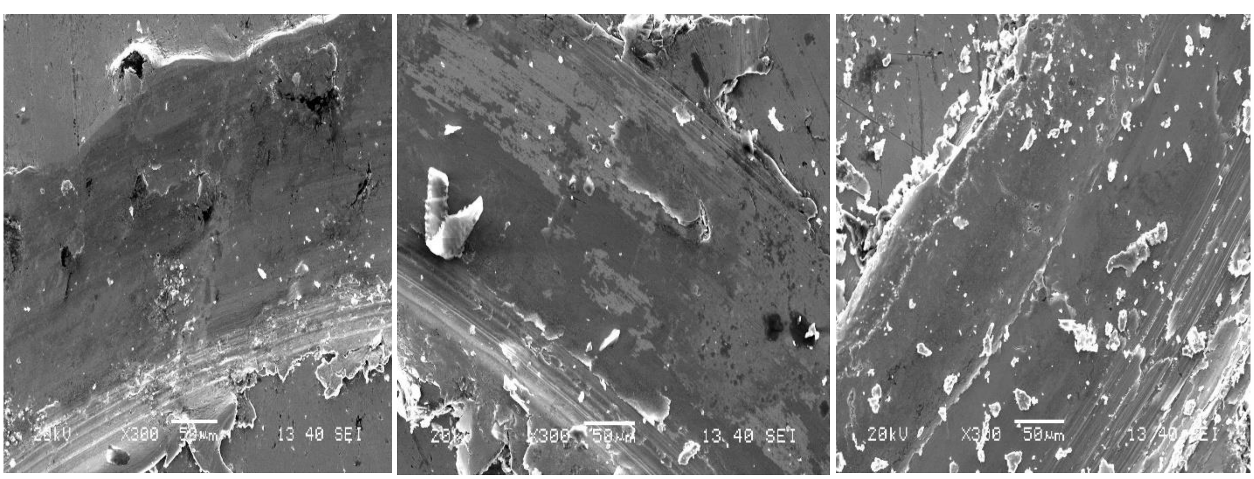
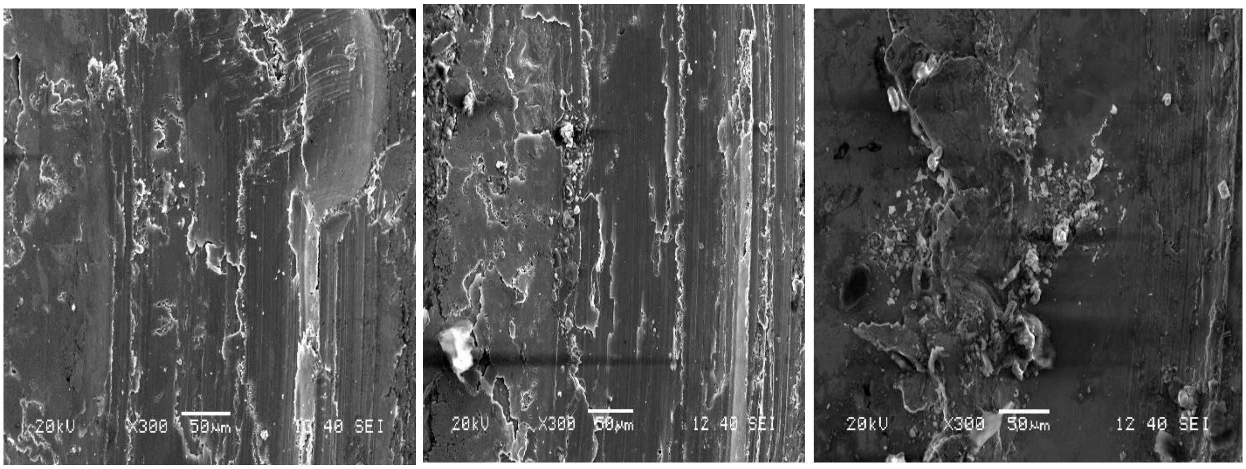


Fig.6.5: (D) EDX image of 200°Cat 2hr of 20min and 30min respectively.



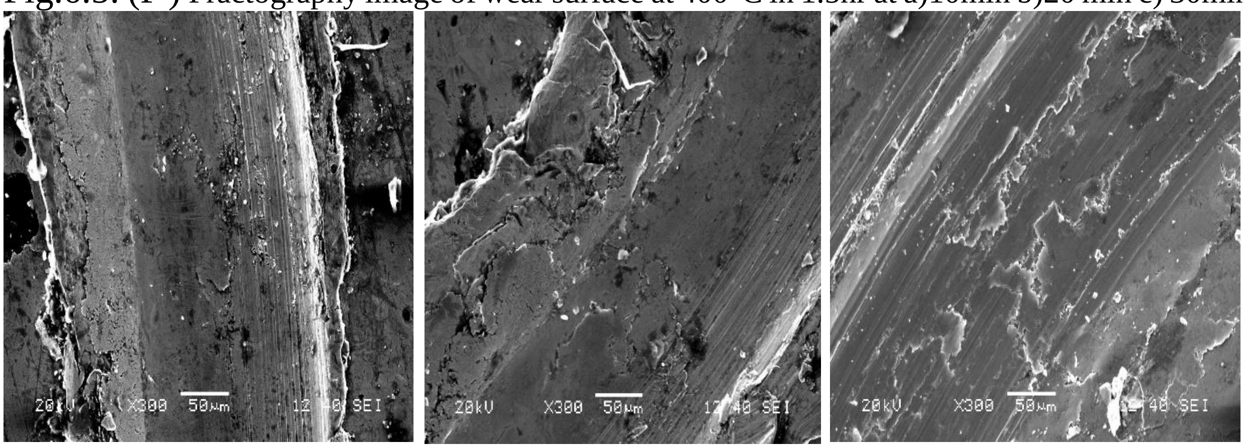
(a) (b) (c)

Fig.6.5: (E) Fractography image of wear surface at 400°C in 1hr at a) 10min b) 20 min c)30min



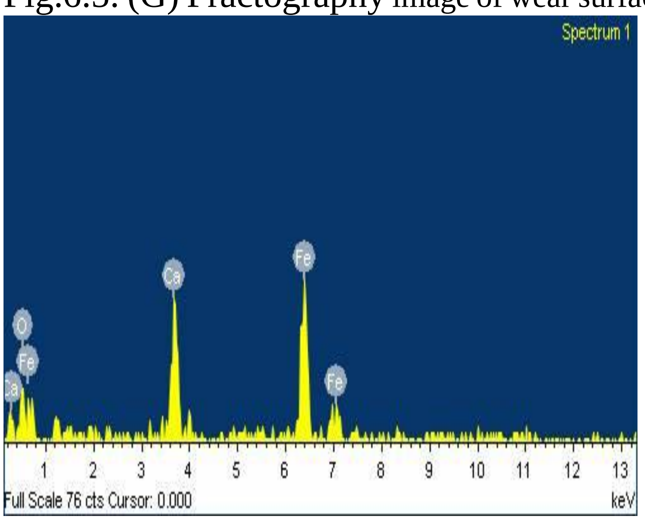
(b) (b) (c)

Fig.6.5: (F) Fractography image of wear surface at 400°C in 1.5hr at a)10min b)20 min c) 30min



(a) (b) (c)

Fig.6.5: (G) Fractography image of wear surface at 400°C in 2hr at a)10min b)20 min c) 30min



Element	Weight%	Atomic%
O K	19.50	43.75
Ca K	17.80	15.95
Fe K	62.70	40.31
Totals	100.00	

Fig.6.5: (H) EDX image of 400°C at 1hr of 30min respectively.

Study of the X-ray diffraction:

The X-Ray diffraction pattern are shown in that figure 7.6, for different tempering temperature and time. After analyzing diffraction peaks of respective sample it was found that sample tempered at 200C have martensitic phase, (101) (200) (211), with retained austenaite (111) (200) (311). Whereas sample tempered at 400C for varies time appeared to have martensite and ferretic phase.

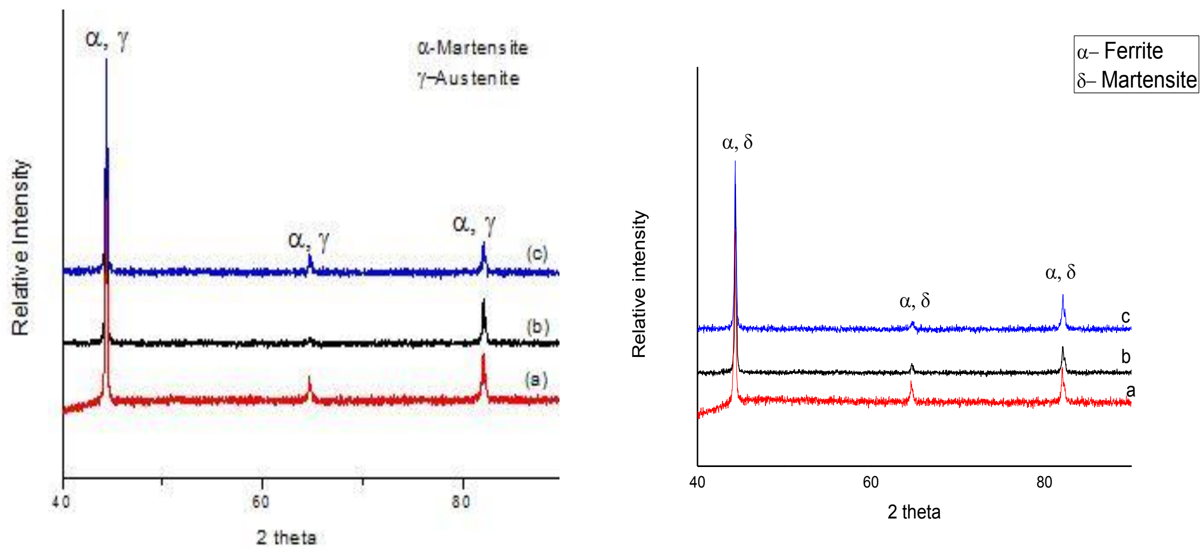


Fig. 6.6: XRD analysis data of tempered sample with different matrix phases.

While, in tempered samples for 2 hours the amount of retained austenite is little higher than other samples. The amount of retained austenite increases with time.

7. Conclusion

The result obtained from present work can be summarized in the following points.

1. By increase tempering time martensitic content reduced resulting in increase of ductility and reduction of ultimate tensile strength and yield strength,

2. Within the temperature range of 200°C–400°C, there is a sudden increase in impact strength and elongation percentage, whereas within the same temperature range, the ultimate tensile strength and yield stress decreased.

3. Longer duration of tempering period at 200°C & 400°C increases the elongation percentage for tempering periods up to 120 min, and ductility increases

4. Whereas with increase in tempering time light pits were also observed in every specimens & were increased in the specimen tempered for 120 minutes. On the other hand specimens tempered at 400°C for various time showed pits around the spherical nodules suggesting dominating nature of ductile failure mode

5. As the tempering temperature & time increases the impact energy increases, this means the energy absorption capacity of Spheroidal graphite iron increases as the time & temperature of tempering increases.

6. The weight loss of specimens tempered at 400°C are higher than that of 200°C due to ferritic matrix and increasing ductility with increased tempering temperature.

7. The major wear mechanism involved was observed to be adhesive type signified by presence of delaminated layer. Tempering temperature and time was found to have very little effect on specimen tempered at 200°C for 2hr under 30 minute dry sliding condition. It was observed that abrasive wear mechanism was involved for this case.

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